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FINAL REPORT

INTERACTION OF CHRONIC COLD EXPOSURE AND
PHYSICAL TRAINING UPON HUMAN BODILY TOLERANCE TO
COLD

Professor K. LANGE ANDERSEN

INSTITUTE OF WORK PHYSIOLOGY
OSLO, NORWAY

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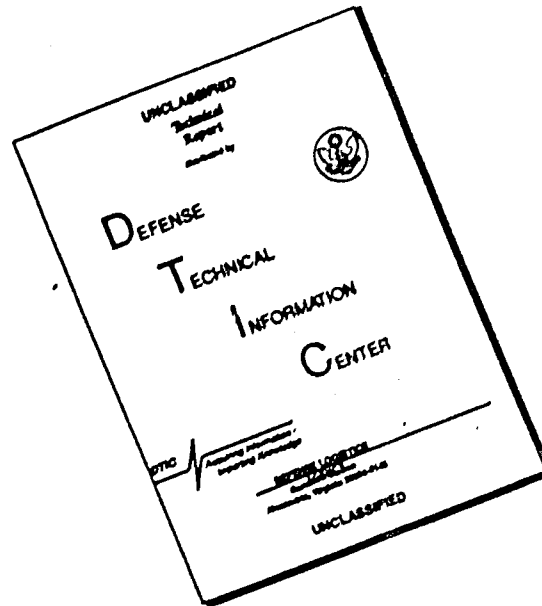
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CONTENTS

	Page
I. Introduction	1
1) Review of relevant literature	1
2) Objectives of the study	7
3) Plan for the investigation	7
4) Subjects	9
II. The physical training and its effect upon health and physiological indices of physical fitness	10
III. The cold exposure	21
IV. The diet and caloric balance	25
V. The effect upon cold tolerance	30
1) Thermal and metabolic responses during a night of exposure to warm and to moderate cold	30
2) Sleep and muscle activity during general body cooling	45
3) Aspects of peripheral circulation	58
4) Pressor reaction to severe appendage cooling	79
VI. General discussion	96

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I. INTRODUCTION.

1) Review of relevant literature.

The relationship between cold tolerance and physical fitness has been the subject for controversy. The present study on a group of young men, not particularly fit for heavy work, and without any unusual tolerance to cold, was undertaken to answer some of the questions concerning the interrelations of the physiology underlying these two characteristics.

The physiological adjustments associated with increased tolerance to cold involve mainly the bodily heat production and the peripheral circulation, both being under the influence of the thermoregulatory center within the central nervous system. These two physiological parameters will therefore be reviewed in relation to cold acclimatization and physical training, the two main factors known to increase respectively cold tolerance and physical fitness.

Metabolism as affected by cold acclimatization.

Scholander et al. (1) investigated the metabolic and thermal effect associated with cold acclimatization by having eight young students camping in the mountains during the cool autumn season, poorly clothed and with insufficient night protection to keep warm at the basal heat production. After six weeks they had developed a considerably increased resistance to cold. When tested under standard cold conditions they slept well and maintained warm surface with a fairly steady heat production elevated 50 - 60 % above the normal basal level. On the average their basal metabolic rate rose about 20 %. Unacclimatized subjects resting under the same cold condition slept poorly, did not mobilize so much heat, shivered in bouts and suffered a considerable skin cooling, particularly on the feet.

Indigenous peoples of the Arctic like the Eskimos (2), the Lapps (3), and the Indians (4, 5) resembled the acclimatized Caucasians by having a tendency to sleep and to rest more comfortably under similar standard cold conditions. Unlike the acclimatized Caucasians they did not enjoy any higher heat production when moderately cold exposed using the standard test. Nor have studies of primitive naked people living in the tropic (6, 7, 8) or investigations of transient populations in the Antarctic revealed any

metabolic type of cold acclimatization (9, 10). Wyndham (11) claims that the mild cold stress used in the standard all-night experiments may be insufficient for producing differences in metabolism. He advocates a testing procedure in which the subjects are exposed to a variety of cooling environments, ranging from warm comfortable to severe cold, each lasting for two hours. He was only able to detect metabolic differences during more severe general body cooling naked at 5 °C. In such acute cold experiments the greatest tolerance to cold was associated with the highest metabolic response. Wyndham's concept is relevant to a situation in which the awaken and active man is exposed to cold. But he overlooks the fact that in a such situation man can produce heat by muscular activity, by shivering, but much more important by performing work, and to an extent that can make him warm, even when he is naked, and under rather severe cold. This has been demonstrated in several studies (12, 12, 14, 15); even by Wyndham himself (16). Man's ability to cope with moderate or severe cold is related to his capacity to raise the metabolism through muscular activity. The relevant test for this characteristic is the determination of maximal oxygen uptake. Furthermore, Wyndham does not consider the apparent fact that an essential criterion of tolerance to cold is the capability to sleep and to rest comfortably when cold exposed. For any man, sleep and comfort is impossible under severe cold exposure. Therefore, one can only hope to demonstrate differences in tolerance with regard to sleeping ability under rather mild cold conditions. Better ability to sleep and to rest comfortably in the cold can take place under three different physiological conditions:

- 1) By allowing a reduction of the heat content of the body ("hypothermic acclimatization")
- 2) By increasing the heat production ("metabolic acclimatization")
- 3) By reducing the heat loss from the body ("insulative acclimatization").

This concept forms the basis for the all-night test procedure. In this test a relatively mild cold stress is used, designed to allow moderately general body cooling at the basal heat production.

Considerable information is now available concerning how man living under different climatic conditions reacts to the standard all-night cold test (1, 2, 3, 4, 5, 6, 7, 8, 17). Despite the rather intensive work which has been undertaken, the variety of patterns of responses makes it impossible to give a complete and clear picture of how man physiologically adjusts himself to sleep and rest in a cold climate.

A constant finding in many cold acclimatization studies has been a 10 - 20 % higher metabolism during rest and sleep in a comfortable warm environment, than usually found in people unaccustomed to living in the cold. Remarkable in this respect are the coastal Alutsk Indians of the Southern Chukotka Archipelagos, whose resting metabolism when sleeping in a warm comfortable environment was 30 - 40 % higher than usually found in Europeans. They required hardly any additional metabolism on the standard cold exposure to reach the same heat production as usually seen. Also the great cold resistance found in a Nepalese pilgrim was attributed by Pugh (18) to an elevation of the resting non-shivering metabolism.

The literature is abundant of controversial reports concerning the effect of cold acclimatization upon BMR (for references see O. Wilson 19, Burton and Edholm 20). That many investigators have failed to demonstrate any effect of cold acclimatization upon BMR may be because the usual clinical method has been employed in the measurement of metabolism. The all-night measurements of metabolism which were used in the above mentioned studies, are considered to be much more meaningful, for testing BMR as well as for measuring metabolic response to cold, than the ordinary clinical method, which only covers a period of 10 - 15 minutes.

Since the basal metabolism is elevated only by 10 - 20 %, the cold acclimatized peoples' advantage may be of some significance during mild cold exposure, but becomes considerably less when the cold stress is severe. As the cold stress has varied greatly in tests purporting to measure tolerance to cold, there is no wonder that the results are very often conflicting. Experiments in which nude human subjects lived under standardized laboratory conditions in climatically controlled cold rooms and unassociated with physical training, have not produced evidence that cold acclimatization results in increased basal metabolism during moderate cold exposure (21, 22). It is therefore possible that the higher heat production found in subjects cold acclimatized by living under Arctic or mountainous field conditions, is rather an effect of the greater muscular activity usually associated with field acclimatization, than a result of the cold exposure.

Metabolism as affected by physical training.

Higher basal metabolism has been found in athletes than in subjects engaged in a sedentary work, and also people doing strenuous manual work usually possess higher basal metabolic rates than workers from the more

sedentary professions, although contradictory reports exist (23, 24). These comparative studies indicate that physical training may bring about an increased BMR. This hypothesis has, however, not been fully verified by training experiments performed on man (22) or on animals (25).

The basal metabolic rate of the subjects studied by Scholander et al. (1) rose 15 - 25 % during the period of cold acclimatization and vigorous physical activity. In view of a possible increased BMR with training, doubt may be raised as to the interpretation of this phenomenon. Also the elevation of heat production during moderate cold exposure found in the same subjects, may merely reflect the increased basal metabolic rate rather than being a physiological characteristic in itself. Further studies are required to work out this problem.

The capacity for elevating the metabolic rate in muscular exercises is increased by training, and up to 70 or 80 % higher maximal oxygen uptakes are found in athletes than in non-athletes (26). This is an important physiological characteristic in relation to cold tolerance, because higher aerobic capacity includes higher ability to produce heat through muscular exercise. A person more fit for muscular work is therefore also more fit to cope with cold. The development of increased aerobic capacity is known to be related to increased muscle mass, increased vascularization of the trained skeletal muscles and raised functional dimensions of the circulatory and respiratory organs. However, the exact nature of the possible elevated basal metabolic rate which comes with training, is obscure.

Peripheral circulation as affected by cold acclimatization.

Investigations of the vascular response to cooling have convincingly shown that greater tolerance to cold is associated with vascular phenomena such as reduced pressor response to appendage cooling (27, 28), a quicker onset of the cold induced vaso-dilatation (29, 30, 31, 32), and a faster rewarming of cooled extremities, on increased heat production due to muscular exercise (14, 15). The most common interpretation of the rather complex vascular reactions and their complex regulations is that they are local effects of an adaptive mechanism which lies within the central nervous system (28).

In the studies by Scholander et al. (1) referred to introductory, it was found that with increased tolerance to cold comes warmer surface when tested under the standard cold condition. The greater cold resistance

observed in Arctic people is also associated with somewhat better ability to maintain higher surface temperatures during general body cooling, indicative of a greater blood flow to the skin of the peripheral body parts. Increased ability to keep the skin surface warm under general body cooling has been found in a number of other cold acclimatization studies (21, 22, 33, 34, 35). It has been demonstrated that the advantage only is measurable under rather mild cold conditions (28, 36). The warmer surface upon cold exposure is the opposite reaction of what would have been expected if an "insulative type of cold acclimatization" had developed. However, warmer hands and feet make these body parts more fit for work, tend to reduce frost injuries and contribute to comfort under cold conditions.

The blood flow mechanism underlying the differences in skin temperature during cold exposure has never been satisfactory worked out.

Discrepancies exist concerning blood flow through the hands during local cooling of cold acclimatized and unacclimatized subjects (30, 37, 38). This may partly be explained by the experimental procedure applied to study this phenomenon. Water is mostly used for local cooling, and the cooling power of water is 25 times as great as for air. Hellström (28) was able to detect quite impressive blood flow differences between cold habituated fishfilleters and indoor-living workers when using air-cooling instead of water cooling.

By using the all-night test of cold exposure, the differences between cold habituated and unhabituated subjects' feet skin temperatures are small, but definitely of significance. Two types of differences of the cooling of the feet are usually seen between cold acclimatized and unacclimatized subjects:

- 1) The skin temperatures of acclimatized subjects are higher at the beginning of the experimental night and remain higher all night through (Scholander's subjects).
- 2) The skin temperatures of acclimatized subjects are higher at the beginning, but approach the temperatures of the unhabituated subjects during the course of the experimental night.

It is considered important to work out the blood flow mechanism underlying these differences in peripheral skin cooling.

Adams and Heberling (34) and Keatinge (22) attribute reduced peripheral skin cooling upon general cold exposure to increased physical fitness. This suggestion makes it necessary to review what is known about the effect of physical training upon peripheral blood circulation.

Peripheral circulation as affected by physical training.

The greater muscular performance which comes with training is known to be associated with a greater capacity to irrigate the muscle tissue with blood during exercise, dependent at least to some extent upon better vascularization (39, 40). Also physical training is known to increase the blood volume (41) which in itself will tend to increase blood flow through the peripheral body parts, other factors influencing blood flow being the same. The most striking effect of physical training is a reduction of the resting heart rate. This phenomenon has been interpreted as meaning reduced activity of the sympathetic nervous system upon the cardiac muscle. If this is a general phenomenon, there is hypothetical possibility that physical training effects the peripheral circulation by reducing the activity of the sympathetic nervous system upon the smooth muscles of the vessels, or that it reduces the sensitivity of these muscles for nor-adrenalin.

What the relationship between physical training and peripheral circulation - and the nature of this - may be, the observations by Adams and Heberling, and by Keatinge, call for further studies.

Cold tolerance and physical fitness.

Adams and Heberling measured physical fitness by determining heart rate recovery from a standard work load, while Keatinge merely stated that his trained subjects have improved their physical fitness. The most acceptable physiological index of physical fitness is the maximal oxygen uptake, because this characteristic tells how much energy can be mobilized for muscular work by aerobic chemical processes. The relationship between maximal oxygen uptake and heart rate recovery is weak (42), and consequently the improvement of fitness in terms of aerobic work capacity in the above mentioned study by Adams and Heberling is questionable, despite a quite impressive improvement in the heart rate recovery index. Maximal oxygen uptake has been determined in subjects whose tolerance to cold is also measured. Four Alucaluf Indians (43) possessing an aerobic work capacity comparable to untrained Oslo students, had a remarkably high resting non-shivering metabolism, and showed less skin-cooling on the extremities upon moderate cold exposure than unacclimatized Caucasians. Similar high tolerance to cold associated with low fitness was also noted in eight Eskimos (44). On the other side the greater resistance to cold observed in Athabaskan Indians (45) and Lapps (46) were associated with a somewhat better fitness than usually found among sedentary men.

That greater resistance to cold in terms of elevated metabolism and less peripheral skin-cooling upon moderate cold exposure not always is associated with high maximal oxygen uptake, does not exclude the possibility that increased muscular activity over a period of time may bring about such bodily effects without changes in aerobic work capacity. There thus appears to exist great uncertainty about these problems which requires further experimental work for elucidation.

2) The objectives of the present study.

The objective of this study was to obtain experimental data to answer the following questions:

1. Does muscular training induce physiological adjustment in the metabolism and peripheral circulation so that the tolerance to cold becomes increased?
2. Does cold exposure have any additive physiological effects to those induced by the physical training?

For this purpose healthy young men were subjected with vigorous physical training for five weeks. Half of them were also cold exposed by sleeping under cold conditions. Measurements of aspects of the physiology underlying cold tolerance and physical fitness were undertaken before and after this five week period.

3) Plan of the investigation.

Phase I. In this preliminary period the measurements of fitness and cold tolerance were performed at the permanent laboratories at the Institute of Work Physiology in Oslo. The 19 subjects lived at the institute for the four weeks required to perform all the tests. During this period the subjects were kept physically inactive.

Phase II. During this phase, which lasted for five weeks, all subjects were physically trained to the same extent. In addition half of them were cold stressed. During this training period they lived at Rjukan Fjellstue, a small mountain lodge situated at the southern edge of the Hardangervidda at an altitude of 900 m corresponding to the tree line.

The warm group was housed in small log cabins furnished with stoves so that they could be properly heated. These subjects slept in ordinary beds with sufficient blankets to keep them normally warm and comfortable.

The cold subjects were cold exposed during the nights. Their quarters gave protection against rain and heavy wind, but were unheated and so poorly insulated that room temperature paralleled the ambient outside air temperature exceeding it by about 1 °C during the nights. They slept naked on beds with mattresses, under a single blanket inside a cotton cover.

The daily regular time schedule was:

7 a.m.	Awakening
7.30-8 a.m.	Breakfast
8 a.m.-12 noon	Work in the surroundings of the lodgement
12-2 p.m.	Lunch
2-5 p.m.	Physical training
6-7 p.m.	Dinner
7-10 p.m.	Leisure
10 p.m.	To bed.

Phase III. Measurements were again made after the subjects having been cold exposed and physically conditioned. Most of the tests were performed at Rjukan Fjellstue where field laboratories were established.

The subjects underwent phase I as a group. They were then divided into two groups matched for body size and physical fitness (table I). Both groups were subjected to the same programme of physical training and manual work, but they differed in cold exposure as mentioned above.

Table I

Physical characteristics of warm and cold subjects.

Cold				Warm			
Subjects	Height cm.	Weight kg.	Fitness ml/min kg.	Subjects	Height cm.	Weight kg.	Fitness ml/min. kg.
1	167	74	42	11	173	79	43
2	169	69	51	12	167	60	48
3	173	71	52	13	176	69	44
4	176	75	41	14	178	72	49
5	178	68	45	15	182	80	44
6	182	84	42	16	183	70	45
7	184	69	52	17	184	78	51
8	184	75	50	18	185	74	47
9	189	83	42	19	193	84	53
10	190	72	37				
Average	179	74,0	45,4	Average	180	74,0	47,1

This subject is separately reported as indicated in the text.

4. Subjects.

Nineteen young men, ranging in age from 19 - 22 years, volunteered as experimental subjects, all of them were in the Norwegian Civil Labour Service instead of in the Military Service for ethical or religious reasons. All of the subjects were medically examined prior to the experiment, and no symptoms or signs of disease were found. One appeared to be under-nourished. It was only later discovered on investigation of the extraordinary improvement of his work capacity that he had for religious reasons undergone a period of two months' starvation prior to the experiment. His data have been excluded from the results of the fitness and diet studies. This case is separately reported (47).

II. THE PHYSICAL TRAINING AND ITS EFFECT UPON HEALTH AND PHYSIOLOGICAL INDICES OF PHYSICAL FITNESS

The functional adjustment to physical training involves particularly the organs related to the transport of the respiratory gases to and from the working muscles. The capacity for oxygen uptake increases, and respiratory as well as circulatory recovery after exercise becomes shorter. The higher aerobic work capacity with training depends upon increased functional dimensions of the heart and the lungs. The blood also develops a higher capacity for carrying oxygen.

The main objective of the fitness studies to be reported here was to evaluate the effect of training and the nightly cold exposure upon the aerobic work capacity and related circulatory and respiratory functions.

Since the general state of health influences the fitness, both fitness for muscular work and fitness in terms of general resistance to cold, this topic will be briefly considered based on the medical records taken before, during and after the experimental regimen.

The training programme.

The increased physical activity of our subjects increased their energy expenditure to an average of 40 - 50 % above that which most of them experience in their normal life, as is discussed in another chapter. Both the systematic training and the engagement in four hours daily work contributed to the elevated energy expenditure. The manual work involved repairs to the gravel roads, ground planning, wood cutting etc. The enthusiasm for this work was rather meagre, and decreased as time went on. This type of manual work was quite unusual for the subjects, who were mostly students or workers in light industry or similar sedentary occupations. The intensity of the daily round of work was never very high, and required probably only a fraction, estimated 25 - 50 %, of the subjects' energy producing capacity. On the other hand, the regular training which was led by an experienced physical instructor, was coached so that the subjects were maximally activated in muscular exercise, usually in bouts several times daily. None of the subjects had any appreciable athletic background, and measurements showed that their fitness prior to the training was the same as the average for sedentary men of similar age. Common types of exercise requiring no special skill for their performances were used to

improve the general fitness. A 12 km course was run twice a week, ball games like soccer, handball, volleyball and basketball were popular sports and were played every day. Two days a week were devoted to interval training. A distance of 100 m was run in about 16 seconds ten times in succession with a pause of one minute between each run. Every physical training session was ended with a 15 - 20 minute period of calisthenics.

Every Saturday an overnight hike to the surrounding mountains was arranged as part of the training programme. Usually a distance of 20 - 30 km was covered during the weekend, every subject carrying a rucksack weighing about 15 kg.

The daily caloric uptake was recorded and the results are given in another chapter. As the energy expenditure reflects the hardness of the training, this topic will be briefly considered. The daily caloric intake averaged 4250 kcal (warm subjects), the energy expenditure was 400 - 500 kcal less than this because of the weight increase. Edholm et al. (1) report that the daily average caloric intake of cadets in the British Army is 3400 kcal. Strenuous manual work jobs like mining or lumbering are known to demand a daily caloric intake of 4000 - 5000 kcal (2). The highest daily energy expenditures reported amount to 8000 kcal, which was the average of three days competitive lumbering in Finland (3). In this connection the energy expenditure of indigenous Arctic people is of interest. The Eskimo hunter's daily caloric uptake is quite low, 2500 - 3500 kcal according to several reports (4).

The total energy expenditure of our subjects was therefore quite high, but it should be realized that the intensity of the training regimen was far below that used in athletics of the endurance type. Our subjects ran a distance of an average of 60 - 70 km a week, which is usually skied in one day by our most successful cross-country skiers when they train for the competitive seasons.

The general state of health.

No symptoms or signs of serious diseases were noted in the subjects during the period of their participation in the project, but minor complaints were quite common. During the first training week the cold subjects complained bitterly of cold during the night, which made normal sleep and rest almost impossible. Headaches, dizziness and a general feeling of discomfort during the daytime were common complaints, and almost everybody tried to get additional sleep under warm comfortable conditions

during the day. This period of general discomfort culminated during the first weekend when the subjects were taken up to the high mountains where they camped. The cold subjects had poor night protection, only one blanket as covering and no protection against the damp ground. When the temperature dropped below freezing during the night, the cold stress became intolerable for most of the subjects who got up and exercised to keep warm. After this miserable experience it was only with difficulty that the experimental staff succeeded in keeping the subjects on the programme. But after this the complaints gradually stopped, and during the last two weeks all the cold subjects slept well and felt fresh and fit when they awoke in the morning.

No such complaints were made by any of the subjects belonging to the warm group, who all slept well and were not exposed to the cold.

One of the subjects in the cold group developed a mild nasal infection associated with a slight elevation of the rectal temperature. This was a transient illness lasting only 4-5 days. The incidence of sneezing and coughing was not more frequent in the cold than in the warm subjects.

During the third week of training most of the subjects complained of sore leg muscles and pains located in the knee and ankle joints. These complaints were of the same type which usually follows after a period of unaccustomed hard physical training. These disorders, though banal, made running, calisthenics, and physical exercise in general painful, and consequently the intensity of the training programme had to be reduced. This was reflected in the caloric intake data which was lower in the last week of the experimental period.

With the exception of these minor complaints, the general state of health was remarkably good. Everybody had excellent appetites from the very beginning, resulting in a steady weight increase. The erythrocyte sedimentation rate which was taken before and after the experimental period, and chest-X-ray, were normal and did not change. The percentage of hemoglobin in the blood increased slightly (Table 1). The heart rate at rest decreased slightly, which is a usual finding associated with training (Fig. 1).

Table 1.

Hemoglobin content of the blood (g/100 ml) before and after the training period. 18 subjects. (Mean and S.D.)

SUBJECTS		Before training	After training
COLD	(9)	16.1	16.7
		\pm 1.14	\pm 1.06
WARM	(9)	16.1	17.1
		\pm 0.45	\pm 1.10
TOTAL	(18)	16.1	16.9
		\pm 0.84	\pm 1.03

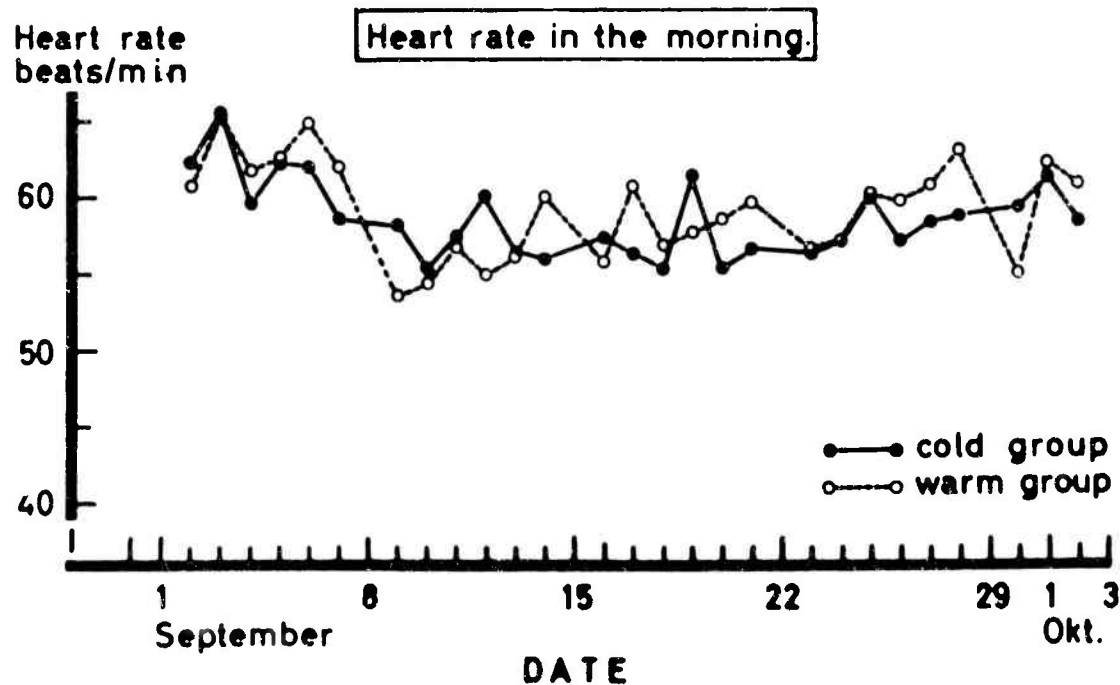


Fig. 1. Average values for resting heart rate.

The systolic arterial pressure at rest was unaffected by the training regimen, while a statistically significant drop in the diastolic pressure was recorded, giving larger pulse-pressure, which was probably related to an increased stroke volume. This problem will be discussed later. The volume of the heart became larger (Table 3) probably due to a dilatation rather than hypertrophy. The enlargement of the heart with training is a usual finding, and this matter and its significance for the functional capacity of the circulation will be discussed later. E.C.G. tracings at rest, using common twelve leads, gave no indication that the training and cold exposure had any effect other than reduction in the rate.

The general health was judged by experienced medical doctors to be improved during the period of training and cold exposure.

Changes in aerobic work capacity and related circulatory and respiratory functions.

The maximal oxygen uptake and related respiratory and circulatory functions were measured and used as criteria of physical fitness. The technique for these measurements has been described in earlier publications to which references are made (5).

On the basis of the preliminary test and prior to the training period the subjects were paired so that the average fitness (max. ml. O_2 /min/kg body weight) was the same for both the cold and warm subjects (see Table 1 in the introductory section). The training regimen had the same effect on the indices of fitness regardless of cold exposure. The results of the respiratory and circulatory measurements taken before, during and after the experimental period are therefore presented for all the subjects as one group.

The average maximal oxygen uptake of the unconditioned subjects averaged 3.48 l/min or 47 ml/min/kg body weight (Table 2) which is essentially the same as found for other groups of young sedentary men (5). This level of aerobic capacity makes these sedentary subjects less capable of performing heavy work than well-trained athletes, who usually have a capacity 50 - 60 % higher (5).

All of our subjects except two increased their oxygen uptake capacity during the five weeks of physical conditioning, but the increase averaged only 6.3 %, which is a statistically significant but fairly small increment. Since the body weight also increased, the oxygen uptake

capacity expressed per kilo body weight remained almost unchanged. The weight increase, amounting to an average of 2.5 kg or 3 %, has been discussed in another chapter, in which it was pointed out that the weight change was associated with increased fatness, and therefore the effect on the weight of the muscle tissue was probably negligible. It therefore follows that the aerobic work capacity, which is a function of the size of the muscle mass, is increased without a corresponding increase of the muscle mass. The increased aerobic work capacity must therefore be brought about by a mechanism by which each unit of muscle mass can consume oxygen at a higher rate.

Table 2.

Maximal oxygen uptake before and after the training period.
(Mean and S.D.)

TEST	Maximal oxygen uptake		
	l/min	ml/min/kg	Max. O ₂ /BMR
Preexp.	3.48 ± 0.37	47.8 ± 3.3	13.9 ± 1.9
Postexp.	3.68 ± 0.36	48.9 ± 2.7	13.3 ± 1.7

The evidence available on the effect of short term training on the aerobic work capacity agrees well with the present finding. Hollman and Venrath (6) conditioned six subjects by having them bicycling four days a week in 20 - 30 minute periods. During the first five weeks the bicycling load was moderate, and no effect of the training upon the aerobic work capacity could be detected. Five weeks strenuous exercise training led to an average increase of 14 %. Holmgren et al. (7) found a 10 - 14 % increase of work capacity (at a heart rate of 170) after a 2 - 4 month period of intermittent training, and a similar effect during 7 - 9 days of continuous ski-training. When convalescents are trained for 4 - 6 weeks, a 20 - 40 % increase in work capacity is usually seen (8). In this respect the increase of maximal O₂-uptake from 2.8 l/min to 4.2 l/min in the subject mentioned earlier is in keeping with studies of convalescents (9).

The heart rate/oxygen uptake relationship deviated before the experimental period from that usually found in young untrained men in as much as the heart rate was higher at all metabolic rates (Fig. 2). The five weeks of physical conditioning had a noticeable effect on these relationship in that:

1. The heart rate became lower at all metabolic rates.
2. An increase in metabolic rate brought about a smaller heart rate increase.
3. Maximal heart rate became lower.

Table 3.

Changes in heart rate during bicycling at 900 kpm/min. 18 subjects.

Heart rate at 900 kpm/min	Before training	After 10 days of training	After 16 days of training	After 23 days of training	After training
Mean	169	147	143	142	149
S.D.	17.8	16.7	13.8	15.8	14.5

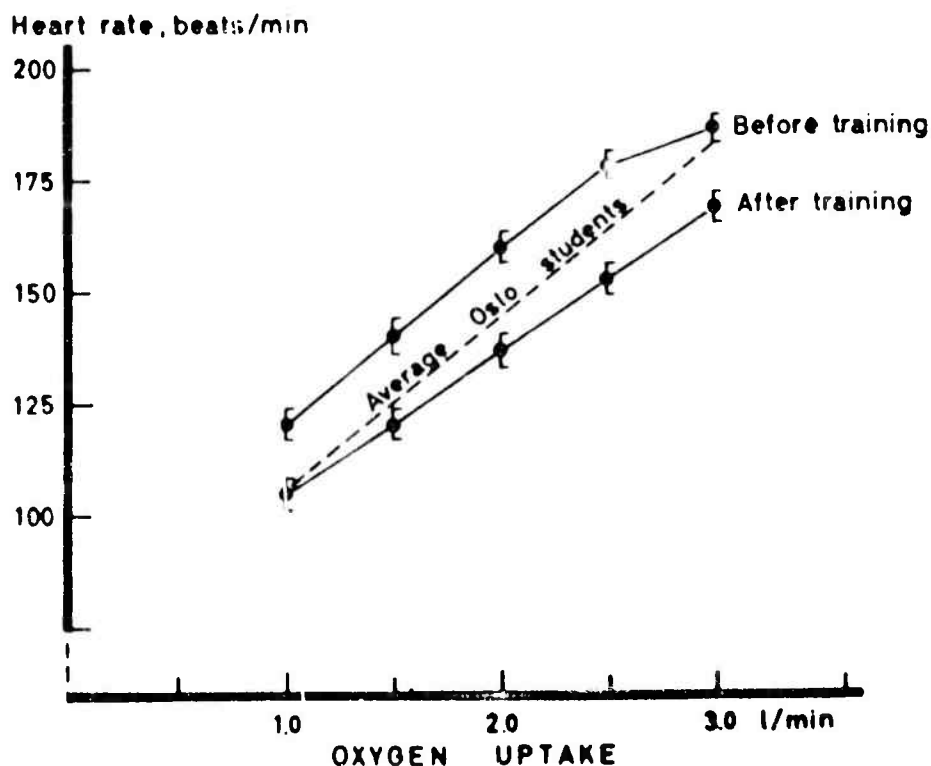


Fig. 2. Heart rate in relation to oxygen uptake. Figures give mean \pm S.E. (vertical lines).

These well-known training effects on the circulatory functions developed quickly. Heart rate during bicycling was tested weekly. The results indicate that the training effect upon the heart rate was fully established within two weeks (Table 3).

The physiological meaning of the change in the "oxygen pulse" (the heart rate/oxygen uptake relationship) is related to the cardiac stroke volume and the A-V oxygen difference. That the stroke volume of our subjects was increased by the training both at rest and during exercise, is indicated from the measurement of heart volume which on average was 15 % higher in the conditioned state (Table 4). Such an enlargement during the course of five weeks is remarkable, and an increase of 50 % in one subject was recorded. If the enlargement of the heart follows the change in oxygen pulse, most of the enlargement probably takes place during the first two weeks of training. The effect on heart size of such short period of training has been reported in two other studies.

Table 4.

Changes in the volume of the heart. Mean and S.D.

Volume of the heart ml			
Before training	708	± 90	
After training	806	± 119	

Holmgren et al. (7) found in training experiments in which work capacity increased by 10 - 15 %, only a negligible and insignificant increase in the size of the heart. Hollmann and Venrath (6) found that maximal oxygen uptake and heart volume increased at the same rate during 5 weeks training (15 %).

Table 5.

Changes in heart rate (beats/minute) at rest and during normal muscular exertion. Mean and S.D.

TIME	Heart rate at rest	"Maximal" heart rate
Before training	196 \pm 6.7	58 \pm 7.3
After training	187 \pm 8.7	53 \pm 6.9

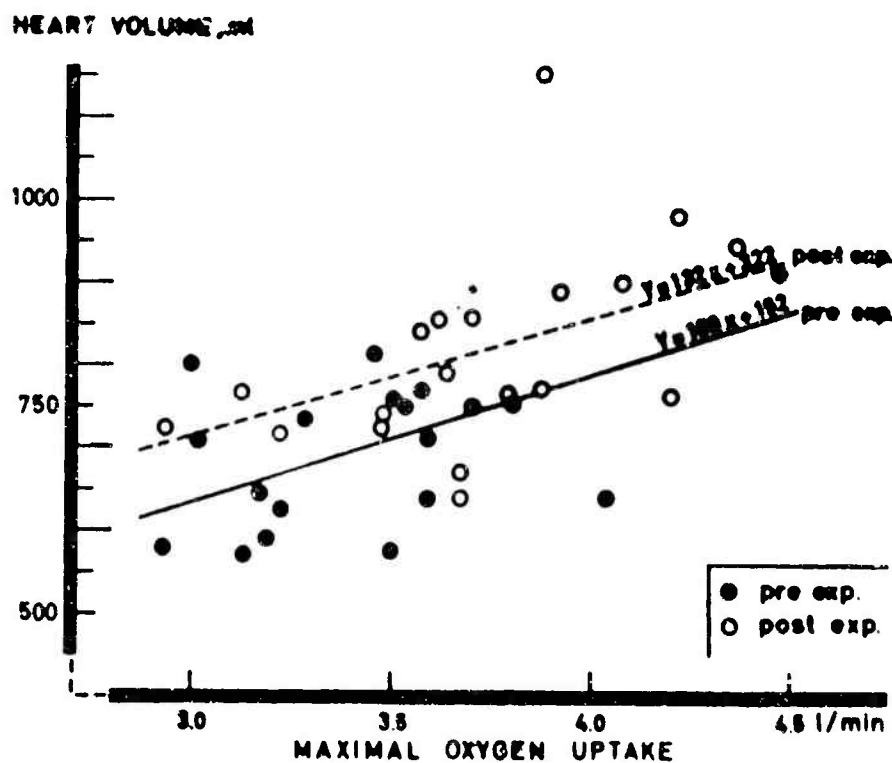


Fig. 3. The relationship between heart volume and max. O_2 .

According to several reports the size of the heart is well correlated to work capacity (10). The relation between max. O_2 -uptake and the size of the heart for our subjects is not so good (Fig. 2). The regression line of our data changed with training in the direction that the volume of the heart increased proportionally more than the increase in aerobic work capacity. The E.C.G. recordings taken before and after the training regimen gave no indication of an increased cardiac muscle mass. The enlargement is therefore most likely a dilatation. This dilatation - as indicated from the enlargement of the "oxygen pulse" and the increased arterial pulse pressure - is probably associated with a greater stroke volume. Therefore the conditioned heart is able to produce the same cardiac output at a reduced rate. Whether or not the "trained heart" is able to produce a greater maximal output, is difficult to assess from the recorded data. The highest recorded heart rate during exhaustive exercises became lower with training (Table 5). This phenomenon was expected since studies in which athletes are compared with non-athletes have revealed such an effect. The values of "maximal" heart rates in non-athletes are usually 190-200 per minute, in athletes "maximal" heart rates are usually 175-185 (5). This may mean that the heart's ability to raise the rate has diminished as a result of the training. But it may also be that there is no need for maximal activation of the heart in the trained state. If this latter concept is correct, it would mean that a heart dilated by training increases its pumping capacity.

It thus seems that the functioning of the heart adjusts quickly to increased activity with an increased stroke volume and a reduced rate, possibly involving a higher pumping capacity. The effect on the aerobic work capacity is a slower process, and requires probably morphological adjustment e.g. hypertrophy of the striated muscles and increased vascularization.

No effect of the short term training could be detected on the pulmonary ventilation (Fig.). There is a tendency to increased maximal values for pulmonary ventilation with training. It is uncertain if this is of physiological significance. It could be a result of greater work in the test purporting to bring about the maximal values after the training.

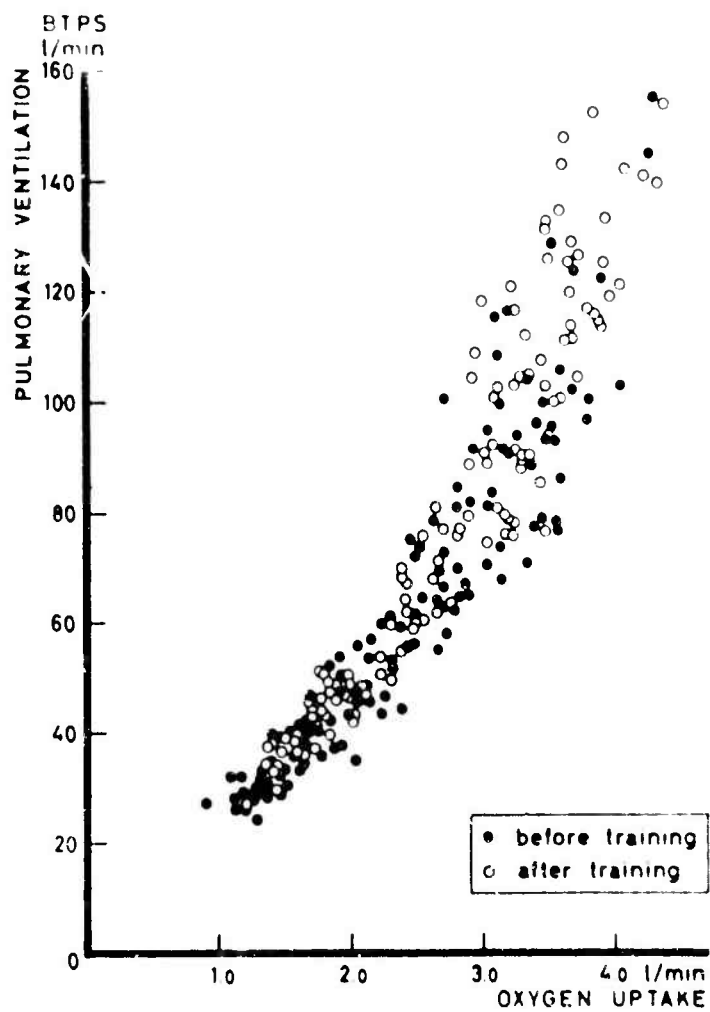


Fig. 4. Pulmonary ventilation in relation to oxygen uptake.

III. THE COLD EXPOSURE

The thermal stress of the environment is considered to depend upon the body heat production and the insulating value of the clothing. While the rate of heat produced is fairly constant at rest and during sleep, it fluctuates widely during the day, dependant upon the muscular activity. The measurements of these fluctuations are difficult to carry out without disturbing the subject and limiting his activity. Clothing can be standardized and its thermal protective value calculated. However, the difficulties involved in matching muscular activity and clothing against the thermal situation in order to achieve a suitable degree of cold exposure in test subjects are so great that it becomes impractical to carry out in field experiments. A suitable cold stress is much more easily achieved during the night time of rest and sleep. The body heat production in this situation is fairly constant, and the fluctuations, at least during mild cooling, are relatively small. Consequently, the thermal stress, e.g. the cooling of the body, can roughly be predetermined by controlling the cooling power of the environment and the protective value of the bed-cover. Furthermore, the cooling of the body can be measured by taking rectal and skin temperatures, which thus serves as measure of the cold stress. In accordance with this concept, the thermal stress used in this study was a mild cold exposure throughout a night which the subjects spent in beds.

During the daytime all the subjects were allowed to adjust their clothing to the environment and to the intensity of work so as to maintain thermal comfort. They ate all their meals in heated quarters, and their leisure time was also spent indoors in comfortably warm rooms. Occasionally, general cold was experienced during the daytime by all the subjects, particularly by the cold subjects who were encouraged to swim in the cold mountain lakes.

Sleeping conditions.

The warm subjects slept in heated and well insulated log cabins with sufficient bed clothes to keep warm and comfortable. The cold subjects slept in a draughty outside shed made of wood boards, which was unheated, but which gave protection against rain and wind. Therefore, the air movement inside was never great. The air temperature inside as

well as outside was recorded three times a night (Fig. 1). The inside temperature was usually higher than the ambient outside temperature by 1°C . The air temperature during the first week ranged between $8 - 12^{\circ}\text{C}$. It gradually became colder, and during the last two weeks was around freezing. Since the bed clothes remained unchanged, the subjects were gradually exposed to a greater cooling power of the environment.

The subjects slept on iron beds, lying on woollen mattresses which gave excellent protection to that part of the body surface resting on it. The cold subjects were nude in beds, except for thin cotton shorts. As covering they had one single layer of blanket inserted in a cotton cover. It was planned to adjust the bed clothes and if necessary remove the mattresses to provide an adequate cold stress. During the first two weeks of cold exposure the cold stress was mild. However, since the subjects' feeling of discomfort was so great in this period, and since the air temperature was gradually decreasing, it was considered that the cold stress was as much as most of these subjects would tolerate for five weeks.

Body temperatures.

In the evening after the subjects were in bed, and in the morning before rising, measurements were made of rectal temperature and of skin temperature of the dorsum of the feet and of the back of the trunk. The warm subjects maintained skin temperatures of $32 - 34^{\circ}\text{C}$ throughout the night, and their rectal temperature showed the normal small decline (Fig. 1). The cold subjects in the morning had skin temperatures lower than the warm subjects by $1 - 2^{\circ}\text{C}$ on the trunk and $1 - 6^{\circ}\text{C}$ on the feet (Fig. 2). The rectal temperature of the cold subjects was also usually lower in the morning than the warm subjects by $0.1 - 0.2^{\circ}\text{C}$. The consistent higher evening rectal temperature noted in the cold subjects is probably related to a vasoconstriction induced by the exposure to cold beds.

Although these differences between the two groups of subjects were small and variable for any one night, the pattern from night to night of the groups was consistent and in keeping with a significant cooling of the cold subjects, not only of the peripheral tissue but also of the body core. By morning the cold subjects were calculated to be in heat debt compared to the warm subjects of approximately 10 kcal.

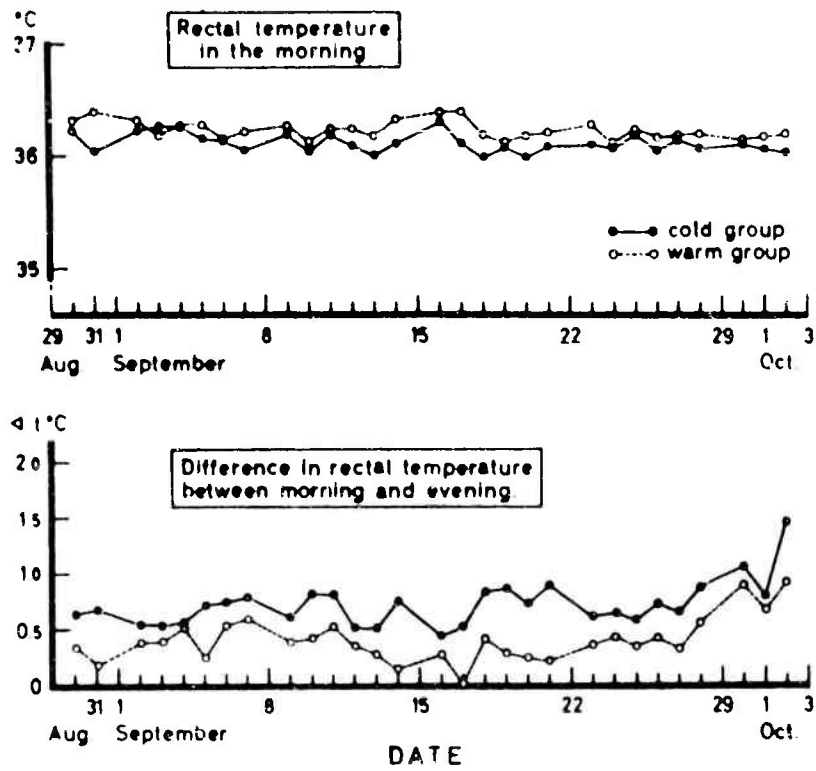


Fig. 1. The rectal temperatures.

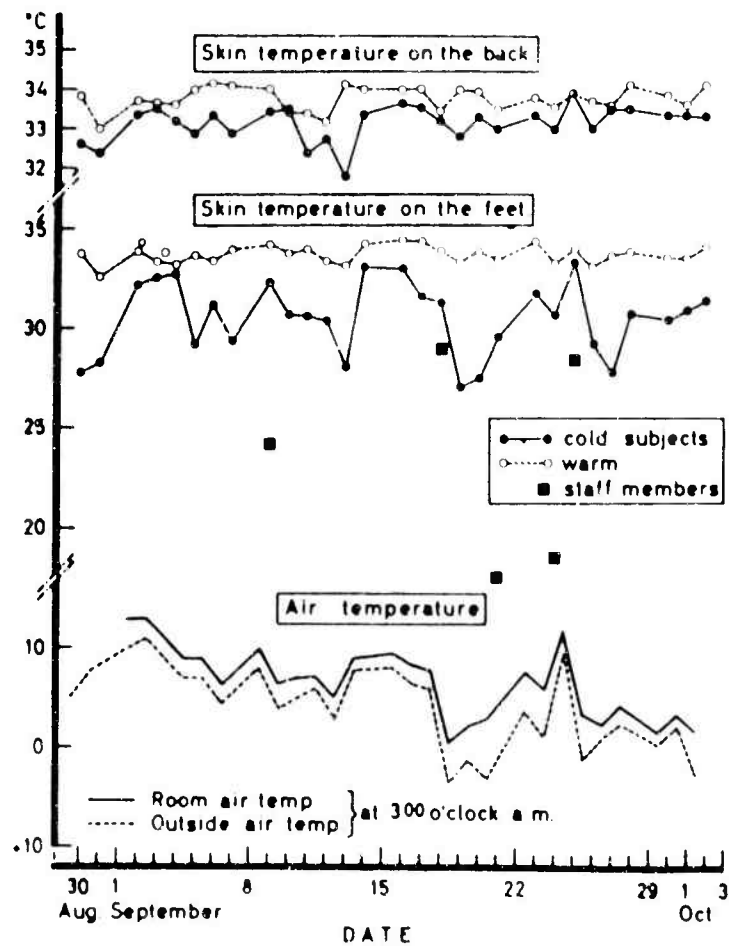


Fig. 2. Skin and ambient air temperatures.

Despite a gradually increased cooling power of the sleeping environment throughout the training period, skin temperatures remained almost unchanged (Fig. 2). The few measurements taken on members of the scientific teams who slept under the same conditions at regular intervals throughout the experimental period indicate that the subjects differed from them in the degree of surface cooling. It will be seen (Fig. 2) that the skin temperature of the feet of these unacclimatized subjects was lower by as much as 5 - 15 °C than the average of the cold subjects. These data therefore indicate that the cold subjects' ability to keep their feet warm under general mild cold exposure had increased.

The subjective feeling of cold stress during the experimental period is described in another chapter. A summary of these observations suggest a gradually increased tolerance to cold in as much as sleep became better and the general discomfort associated with chilling was reduced. This cannot be attributed to a reduced surface or core cooling as indicated from the temperature measurements. As the situation also gave little possibility for reducing the cold stress in the nights by postural adjustments, the observation leaves little doubt that the experimental regimen (e.g. training and cold exposure) reduced the general discomfort associated with chilling by a mechanism lying inside the human body.

IV. THE DIET AND THE CALORIC BALANCE

The diet.

Diet is known to influence the metabolic rate by the specific dynamic action of the nutrients, especially the proteins. Caloric consumption is increased by cold exposure as well as by physical activity. Therefore it was an essential part of the programme to record food intake and changes in body weight and composition. The subjects ate as much as they wanted of food with known contents of fat, protein and carbohydrate for the ease of calculation (1). The daily intake for each subject was recorded.

Although the diet was simple and varied little, the foodstuffs and their preparation was those commonly used in Norway. Bread and butter with cheese, cold ham and sweet jam was served at breakfast and lunch. An egg was added to the morning meal, and a warm dish consisting of either fish or meat balls together with potatoes and vegetables was always served at lunch. The main dinner course varied daily on a weekly schedule, and consisted of either meat or fish together with potatoes and vegetables. The dessert consisted of puddings or preserved fruit, and after dinner one or two pieces of cake (Wienerbrød) was always served. In the late evening a bottle of soft drink and one bar of chocolate ("Kvikk-Lunsj") ended the daily meals. Milk, tea and coffee were served at all meals, and the subjects could have as much as they wanted. On the weekends the subjects went on camping trips, and the composition of the meals for these days was slightly different.

Table 1.

The percentage of the total caloric intake provided by protein, fat and carbohydrate. Daily averages for one week.

DAY	Cold subjects			Warm subjects		
	% Protein	% Fat	% Carboh.	% Protein	% Fat	% Carboh.
1st Day	14	39	47	14	39	47
2nd "	13	45	42	12	44	44
3rd "	14	39	47	15	40	45
4th "	13	38	49	13	40	47
5th "	13	40	47	13	40	47
6th "	9	45	46	10	46	44
7th "	9	45	46	10	46	44
Average	12	42	46	12	42	46

The percentage of fat, protein and carbohydrate remained remarkably constant from day to day throughout the whole training period. The daily average figures for one typical week are given in Table 1 above. It is seen that 12 % of the caloric intake is covered by protein, 42 % by fat and 46 % by carbohydrate. This is comparable to an average Norwegian diet as indicated by recent nutritional surveys (2). In this connection it should be kept in mind that it is reported much higher content of protein in the diet used by people living under Arctic conditions. For instance the proteins contribute 50 - 60 % of the calories of the diet used in primitive Eskimo Communities (3). The high basal metabolic rate, which so frequently is measured in Arctic people, has been attributed to the specific dynamic action of the protein rich diet.

The energy expenditure.

The daily caloric intake of individuals varied greatly from day to day, values as high as 9470 kcal/day were recorded (Fig. 1).

The weekly average remained fairly constant (Table 2).

Table 2.

Average daily caloric intake (k.kal/day)
during the five weeks of training. Means and S.D.

Subjects	1st Week	2nd Week	3rd Week	4th Week	5th Week	Average
Cold (9)	4584 ± 462	4905 ± 634	5045 ± 647	4904 ± 600	4312 ± 543	4750 ± 531
Warm (9)	4137 ± 486	4294 ± 641	4548 ± 644	4409 ± 366	3855 ± 628	4248 ± 493
Difference cold - warm	447	611	497	495	457	502

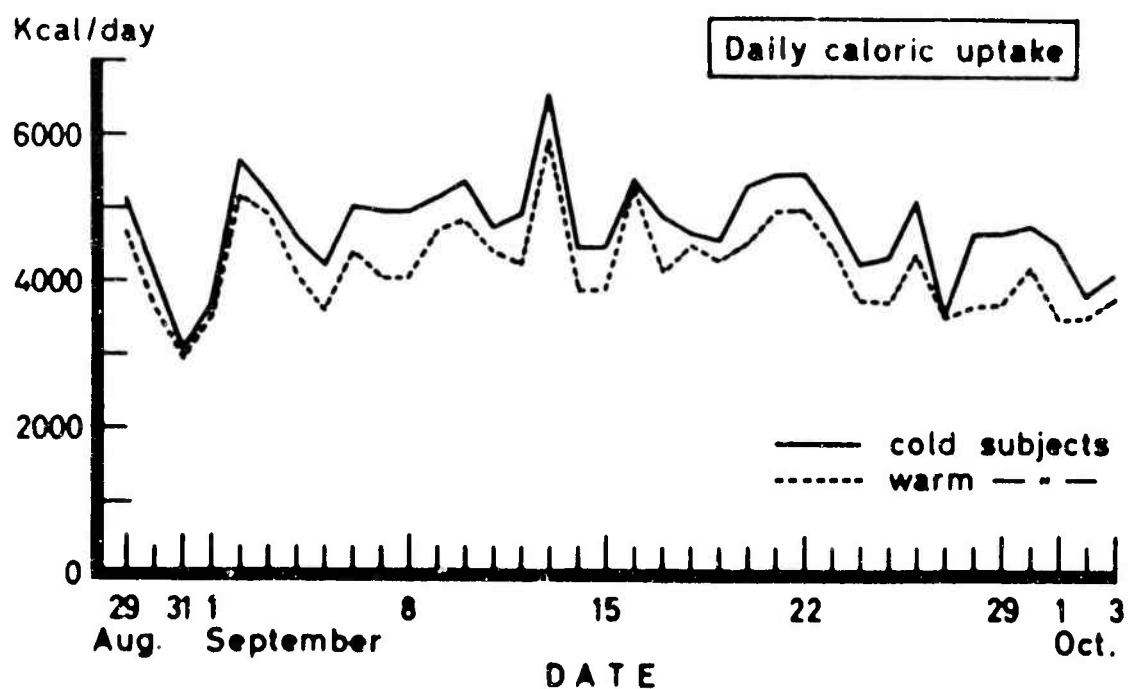


Fig. 1. Daily caloric uptake during the experimental period. Average values of 18 subjects.

A consistent feature was the greater caloric intake of the cold exposed subjects, amounting to about 500 kcal/day. Since the activity pattern during the daytime was the same for both groups, and since the weight increase during the training period was also the same for both groups, it follows that the cold subjects on the average mobilized that much more heat during the nights of cold exposure.

The extra heat production brought about by the night cold exposure characterizes and quantitates the cold stress. This metabolic compensation was sufficient to prevent the rectal temperature from falling any appreciable amount below the normal diurnal decline. A 50 - 60 % increased metabolism above the basal rate sufficient to keep the temperature of the core constant when the nude body is exposed to cold, corresponds to a still environmental air temperature of about 10 °C below the critical temperature.

Most of our subjects were, in their normal life, engaged in jobs of the sedentary type, most likely requiring approximately 2500 - 3000 kcal/day. Taking into consideration a weight increase of 2.5 kg (Table 3) during the course of 35 days, which roughly corresponds to 500 kcal/day, this caloric expenditure of 4250 kcal/day for the cold subjects and 3750 kcal/day for the warm subjects. This is not a remarkably high figure, as will be discussed in another chapter.

Table 3.

Changes in body weight (kg). Mean and S.D.

Subjects	Pre-exp.	After 2 days	After 1 week	After 2 weeks	After 3 weeks	After 4 weeks	After 5 weeks
Cold (9)	73.1 5.7	74.2 8.6	74.6 5.9	75.5 6.5	75.7 5.8	75.8 5.3	75.5 6.6
Warm (9)	73.0 7.7	74.5 5.1	74.1 7.2	75.1 7.3	74.7 7.1	74.9 7.1	75.1 7.1

The body weight and skinfold thickness.

It should be noted that a 40 - 60 % increase of the energy requirement was immediately followed by an increased appetite resulting in a food intake not only sufficient to cover the demand, but overshooting it so that the body weight increased (Table 3).

Table 4.

Changes in skinfold thickness. Figures are means and S.D. (mm) of measurements taken at 10 sites of the body (according to technique by Allen et al. (4)).

Subjects	Before training	After training
Cold (9)	88 ± 18	116 ± 11
Warm (9)	96 ± 19	116 ± 22
Total (18)	92 ± 18	116 ± 18

That the weight increase was mainly increased body fat is apparent from the measurements of skinfold thickness which were higher by an average of 28 mm in the cold subjects, and 20 mm in the warm subjects at the end of the experimental period. Considering the inaccuracy of measuring skinfold, the difference between cold and warm subjects has probably no real meaning.

V. THE EFFECT UPON COLD TOLERANCE

1) Thermal and metabolic responses during a night of exposure to warm and to moderate cold.

An assessment of the combined effects of nightly whole body cold exposure and physical training upon the thermal and metabolic responses to a standard cold stress was achieved by a method which has evolved from one first used by Scholander, et al (9). The method has already been used for comparing the responses of several ethnic groups (1, 2, 3, 4, 5, 6, 7, 8, 9, 10), and has been recommended by the Commission on Physiological Anthropometry of the International Union of Physiological Sciences as one of the standard methods to be used during the IBP for investigating human adaptability. The method involves frequent or continuous measurements of the rate of heat production and body heat content during a night of moderate cold exposure. The nighttime is the period of lowest heat production in man and the longest continuous period without wide variations in heat production. Although sleep during night may alter some aspects of temperature regulation and the response to cold, a long (8-hour) moderate cold exposure at night was chosen for this investigation.

Method

Details of the methods used to measure rates of heat production and the body temperatures have been described and will only briefly be reviewed. For the eight hour cold test, each subject lay inside a standard blanket sleeping bag (Insulation = 1.5 clo^{*}) on a canvas cot and with head sealed in a ventilated plastic hood. Two subjects at a time were exposed to cold inside a portable environmental chamber which maintained approximately 5 °C throughout the night. For the first hour only of a night of cold exposure, each subject was covered by an additional "dyne" or down bag and protected below by two woolen blankets suspended beneath the canvas of the cot. Each cold test on a subject was immediately preceded or followed by a warm test which differed from the cold test in only one

^{*} 1 clo = $\frac{0.6}{\text{Cal/m}^2 \text{ hr}}$. The insulation of the blanket was determined by placing a sample piece on a flat, horizontal heat flow meter and includes the insulation of the overlying still air.

respect, sufficient insulation was provided above and below in order to remain comfortably warm throughout the night.

Heat Production

The rate of heat production was obtained indirectly by measuring the rate of oxygen consumption. The mixed expired air from the ventilated hood was all collected in a field spirometer (11) for 15 (or 17) minutes of each successive 20-minute period throughout the night. The volume of gas collected in the spirometer was metered by first passing through a calibrated dry gas meter. The rate of flow was corrected to standard temperature and pressure dry.

The oxygen content of each collected volume was determined by passing a dried sample through a direct reading Pauling oxygen meter (Beckman, Model C-2) with a range of 120-160 mm Hg. The instrument was calibrated nightly by flushing dry outdoor air through the instrument and reading it at five different pressures below ambient pressure as read by a water manometer in the sealed line to the oxygen meter. See Figure 1 for one such determination of the calibration factor as well as thirteen successive nightly determinations. By this method the difference in oxygen content of the ingoing and outgoing air from the ventilated hood could be determined with an accuracy of $\pm 1\%$ on a single determination. The gas from every fourth collection period was also analyzed for oxygen and carbon dioxide from which the R.Q. was determined. The average R.Q. for the night was then used in the calculation of oxygen consumption to correct for the fact that the rate of flow into the hood may exceed the measured rate of flow out by the difference between the oxygen consumption and the carbon dioxide production.

The subject's head was sealed into the hood by means of a large flexible sleeve made of thin rubber dam. The hood was ventilated at a rate between 30 and 35 liters/min or sufficient to maintain the CO_2 level at less than 1%.

Body Temperatures

All temperatures were measured with 36 gauge copper-constantan nylon coated thermocouple wire. The constantan wire was uninterrupted from the warm to the reference junction. Leads from the + and - terminals of the thermocouple went to a Leeds & Northrup selector switch, Model 8240 and then to a portable millivolt potentiometer, Leeds & Northrup

Model 8636, with a Kipp Model A-70 galvanometer. Thermo-potentials were readily measured to within 1-microvolt and the thermocouple wire that was used was calibrated and thereafter corrected by subtracting 0.05 °C from all readings.

The warm junction of the rectal thermocouple was cast in a poly-vinyl tubing along with a 10 cm length of piano wire for stiffening. The thermocouple was inserted 10 to 15 cm into the rectum and taped in place.

The warm junction of a skin thermocouple was made by stretching the bared end of the constantan wire across an acrylic ring (2 cm diam. and 3 mm thick). The copper wire was soldered to the constantan wire in the center of the ring. The ring was cemented to the skin with contact cement so that the thermo-junction was held firmly against the skin throughout the night. Eight representative skin temperatures were measured in this way. Body temperatures were measured every 20 minutes throughout the night of cold exposure and every 30 minutes during the warm nights. The weighted average skin temperature was computed using the following weighting factors: foot, 0.07; calf, 0.13; thigh, 0.19; chest, 0.18; back, 0.17; arm, 0.15; hand, 0.05; forehead, 0.07.

Environmental Chamber

A portable field environmental chamber was constructed for these tests to obtain a suitable and reproducible sleeping environment without depending upon natural conditions. The walls of the chamber were assembled from 4' x 10' or 4' x 8' sections of 4" thick polyurethane bonded between two hardened aluminium sheets - 3/32". The floor area of the chamber was approximately 8' x 10' and the inside working height was 40". The side walls hinged along the top edge to permit easy access to the subject on either side. Air discharged from the top of an evaporator at one end of the chamber moved back along the inside top of the chamber to the other end where it entered ports in the lower back corner and returned to the evaporator through ducts under a false floor. Air was forced to move by a squirrel cage blower in the evaporator and blowers in the ports of the return ducts. Air movement was perceptible to the exposed skin but was not breezy.

Results

Temperature and metabolic measurements for nearly 100 subject nights were obtained and analyzed. Since the amount of material is so great, it is impossible to present individual responses. Presenting selected representative results seems almost meaningless and not very convincing; therefore we have chosen instead to illustrate our results by means of the group average responses to a given set of conditions. These average results are shown in Figures 2 through 7 and in the Summary Table.

The metabolism and body temperatures of nineteen young Norwegian males were obtained during a night of moderate cold exposure (hereafter referred to as "cold test"), and during a night of sleeping warm (referred to as "warm test") during the month of August. These tests were made before any conditioning to cold or physical training was instituted; therefore, these responses are referred to as the "pre-conditioning" responses. After these and other tests were completed, the men were divided into two nearly equal groups. As was explained elsewhere in this monograph, one group of ten men (hereafter referred to as the COLD Group) was exposed nightly to cold by sleeping in an unheated shed for five weeks with inadequate bed covers. The other group of nine men (WARM Group) slept comfortably warm every night during the conditioning period. Both Groups underwent a vigorous physical training program for five weeks.

In October, after the five weeks conditioning, all subjects were tested again with a cold test and a warm test just as they had been tested before conditioning. These results are referred to as postconditioning responses.

Figure 2 gives the average results for the metabolic response during the warm tests for both WARM and COLD Groups before and after conditioning. The metabolic rate of each individual was expressed in Cal/hr per unit surface area as a way for normalizing the results of individuals of differing statures. The surface area was computed from the weight and height using the DuBois Formula. The rate of heat production was calculated from the measured oxygen consumption assuming that 1/liter oxygen yields 4.8 Cal. of heat. There is no apparent difference between the WARM Group and the Cold Group either before conditioning or after. There is, however, a marked effect of physical training upon both groups. As shown in the Summary Table, the average metabolism of the COLD Group averaged over the period from the beginning of the second hour to the end of the seventh

hour in the warm test increased from 35.2 to 40.6 Cal/hr m² as a result of the conditioning; a 15 % increase which is highly significant. Similarly, the average metabolism of the WARM Group averaged over the same period increased from 35.0 to 39.4 Cal/hr m² due to the conditioning or a 13 % increase which is also highly significant.

The average results for the metabolic response during the cold tests are shown in Figure 3. Again there is no apparent difference between the WARM and the COLD Group either before or after conditioning, but there is a highly significant effect of the conditioning upon both groups. From the Summary Table, we may note that for the COLD Group the averaged metabolic rate from the second through the eight hour of cold exposure increased from 51.6 to 61.4 Cal/hr m² or 19 %; and for the WARM Group, the increase was from 49.4 to 59.3 Cal/hr m² or 20 %.

Not only was there a highly significant increase in the group average for both the WARM and the COLD Groups as a result of the conditioning, but every individual of both groups responded with greater heat production in the cold test after conditioning. Every individual except one member of the WARM Group also had higher rates of heat production during the warm tests after conditioning.

No clear and meaningful differences were obtained for any of the body temperatures for either the cold or the warm tests. For the cold tests the COLD Group showed no differences in the rectal or average skin temperatures as a result of the conditioning, Figure 4; and the group average foot temperatures were only slightly higher (about 1 °C) during most of the night after conditioning, Figure 6, but only because they were initially higher. In fact, the foot temperature fell more from the beginning to the end of the night after conditioning than before. The WARM Group in the cold test also showed no effect of conditioning upon the average skin temperature or foot temperature nor were they different from those of the COLD Group. The group average of the rectal temperature for the WARM Group was actually less after conditioning when the rate of heat production was higher.

We note that the average air temperatures for the cold tests before conditioning were about 2 °C higher than for the post-conditioning cold tests. Recalculating the average skin temperature for both groups on the assumption that the post-conditioning cold tests were 2 °C higher, i.e. at 7 °C as were the pre-conditioning tests, and assuming that the conductance of the body and of the blanket bag are unchanged, we find that the

average skin temperatures would then be 0.2 to 0.3 °C higher and the heat production would be about 3 % less than they actually were at the air temperature of the post-conditioning tests (5 °C). Adding 0.2 to 0.3 °C to the average skin temperatures for the post-conditioning cold tests of both WARM and COLD Groups still does not uncover any significant effect of conditioning upon the average skin temperature of either group. If the air temperature of the post cold tests had been as high as the pre cold tests, then, possibly, the foot temperatures of the COLD Group would have to be significantly higher after conditioning since the foot is nearly isolated from the body and would have cooled somewhat less if the air temperature had been 2 °C higher. It is doubtful whether the foot temperatures of the WARM Group would have been significantly higher under the same conditions.

In the warm tests, there were no differences between the groups with regard to rectal, average skin, Figure 5, and foot temperatures, Figure 6. Neither group showed any significant effect of conditioning upon any temperature with one exception; after conditioning, the average skin temperatures of the WARM Group were significantly lower than before and by about 0.4 °C.

The responses of the two groups to testing before and after conditioning may be compared in another way by computing a term called the "tissue conductance" for the whole body. Tissue conductance is a kind of circulation index since the conductance of heat from the core to the skin is a function of the blood flow to the skin. Tissue conductance is computed by dividing the rate of heat loss from the skin by the difference in rectal and weighted average skin temperatures. Rate of heat loss from the skin is calculated as the rate of heat production minus 8 % of the rate of heat production (the approximate amount of insensible heat loss from the respiratory tract) plus rate of loss of stored heat. Stored heat is calculated as $(0.7T_{\text{rectal}} + 0.3 T_{\text{avg. skin}}) \times 0.83 \times M$, where 0.83 is the specific heat and M is the weight. The tissue conductances of both COLD and WARM Groups throughout the night of warm and cold tests before and after conditioning are shown in Figure 7. These results are calculated from the group average data for metabolism and rectal temperatures given in Figures 2 through 5. For calculation of tissue conductance, the night was divided into 5-equal periods with one hour period at the beginning of the cold tests. The results for tissue conductance given in the table are averages for the latter four-fifths of the night. There appears to be a 10 to 15 % increase in the

tissue conductance in both groups in the cold test resulting from the conditioning but no apparent difference between the WARM and COLD Groups.

Discussion

These results provide convincing evidence that physical training increases the resting rate of heat production in man by about 15 % and enhances his ability to respond to a moderate cold stress by about 20 %. They also show that there is no apparent additional heat production attributable to nightly experience with cold exposure. These results also reveal no apparent and meaningful effect of physical training or nightly cold exposure upon central or peripheral body temperatures with the possible exception that the foot temperatures of the cold experienced men may have been slightly higher.

We were concerned about the possibility that the standard cold stress that we used might be severe enough to mask any small difference that might exist between the COLD Group and the WARM Group. Therefore, we ran all the post-conditioned subjects through a very moderate cold test by placing a 3-inch thick mattress on the cot and having the subjects sleep on this inside the blanket bag and with the air temperature again held at about 5 °C throughout the night. This time the average rate of heat production from the second through the eighth hour of the COLD Group was 46.8 Cal/m² hr and of the WARM Group was 45.4 Cal/m² hr. In view of the slightly higher metabolism of the COLD Group in the pre-conditioning warm and cold tests, this small difference does not appear to be significant. The average foot temperature of the COLD Group over the final two hours of the very moderate cold test was 27.2 °C compared with 17.8 °C for the same two hours of the standard cold test. The same two average foot temperatures for the WARM Group were 26.5 °C and 18.1 °C respectively. Again the differences are not great enough to be significant, therefore we conclude that there were no detectable differences between the COLD and the WARM Groups attributable to the nightly cold experience of the COLD Group.

We cannot conclude from these results that nightly cold exposure alone may or may not have an acclimatizing effect upon the rate of heat production or the body temperatures of man. We might suppose that it would have insofar as muscles are conditioned by shivering as they are by physical training.

The metabolic results reported here are closely parallel to those obtained by Scholander, et al (9) on an earlier study on Norwegian youths on the Hardanger vidda although they have been interpreted differently. The markedly higher skin, and especially foot, temperatures after cold exposure and training on the men of the earlier Hardanger vidda study have not been seen in this study for an unexplained reason or reasons.

Summary Table

The Metabolism, Rectal, and Weighted Average Skin Temperatures of each subject were averaged from the second through the eighth hour of the night of cold exposure; and from the second through the seventh hour of the warm night. The results in this table are the group averages of the average results of ten individuals exposed nightly to cold for 5 weeks (COLD Group) and of nine individuals sleeping comfortably warm for 5 weeks (WARM Group). Results are given for both groups before and after 5 weeks of vigorous physical training concurrent with the thermal exposure (Pre- and Post-Conditioning).

A. Average Metabolism

Group and Test	Pre-Conditioning Kcal/m ² hr	Post-Conditioning Kcal/m ² hr	Difference Kcal/m ² hr	Value
COLD, cold test	51.6	61.4	9.7	0.001
COLD, warm test	35.2	40.6	5.4	0.005
WARM, cold test	49.4	59.3	9.8	0.001
WARM, warm test	35.0	39.4	4.4	0.008

B. Average Rectal Temperature

Group and Test	Pre-Conditioning °C	Post-Conditioning °C	Difference °C	Value
COLD, cold test	36.25	36.22	-0.03	0.5
COLD, warm test	36.32	36.28	-0.04	0.5
WARM, cold test	36.18	35.96	-0.21	0.10
WARM, warm test	36.37	36.31	-0.06	0.5

C. Average Weighted Average Skin Temperature

Group and Test	Pre-Conditioning °C	Post-Conditioning °C	Difference °C	Value
COLD, cold test	30.8	30.8	+0.01	0.50
COLD, warm test	34.4	34.2	-0.16	0.50
WARM, cold test	30.5	30.3	-0.21	0.20
WARM, warm test	34.4	34.0	-0.37	0.025

D. Tissue Conductance

Group and Test	Pre-Conditioning Kcal/m ² hr °C	Post-Conditioning Kcal/m ² hr °C
COLD, cold test	9.8	10.8
COLD, warm test	17.6	19.4
WARM, cold test	8.8	10.2
WARM, warm test	17.1	16.2

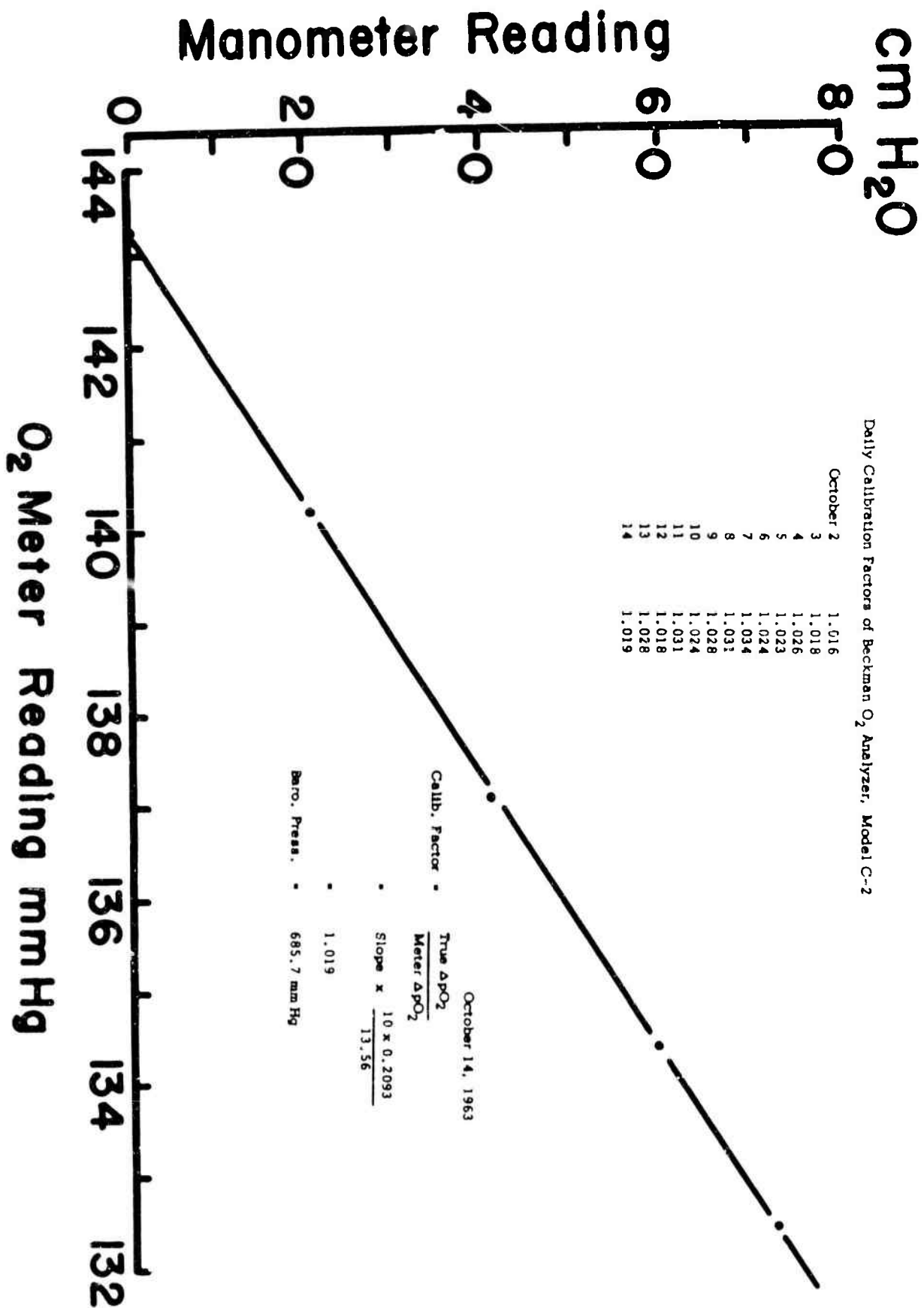


Figure 1.

Figure 2.

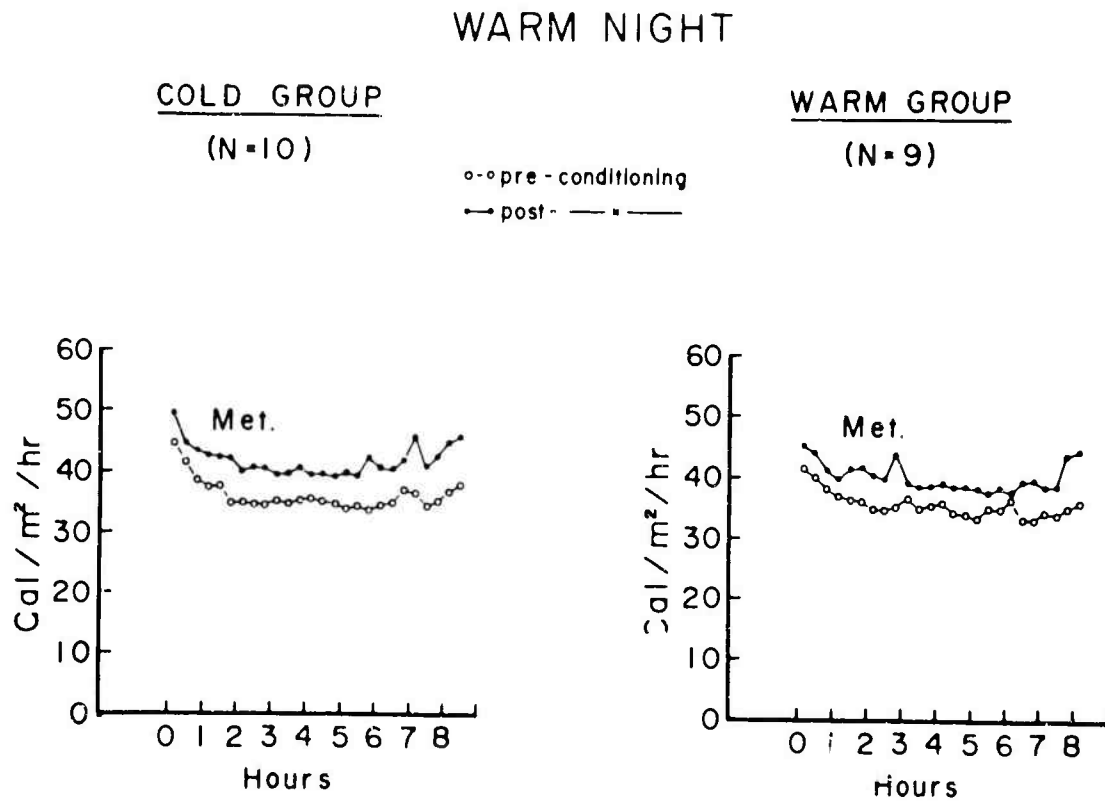


Figure 3.

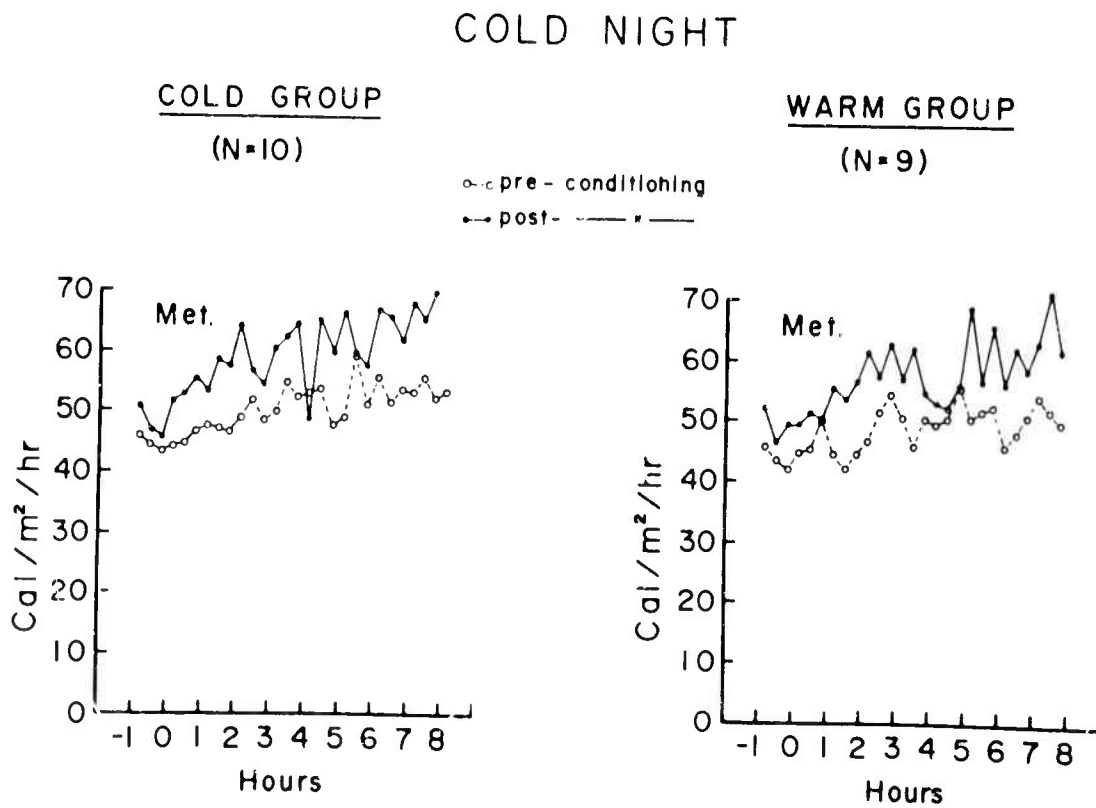


Figure 4.

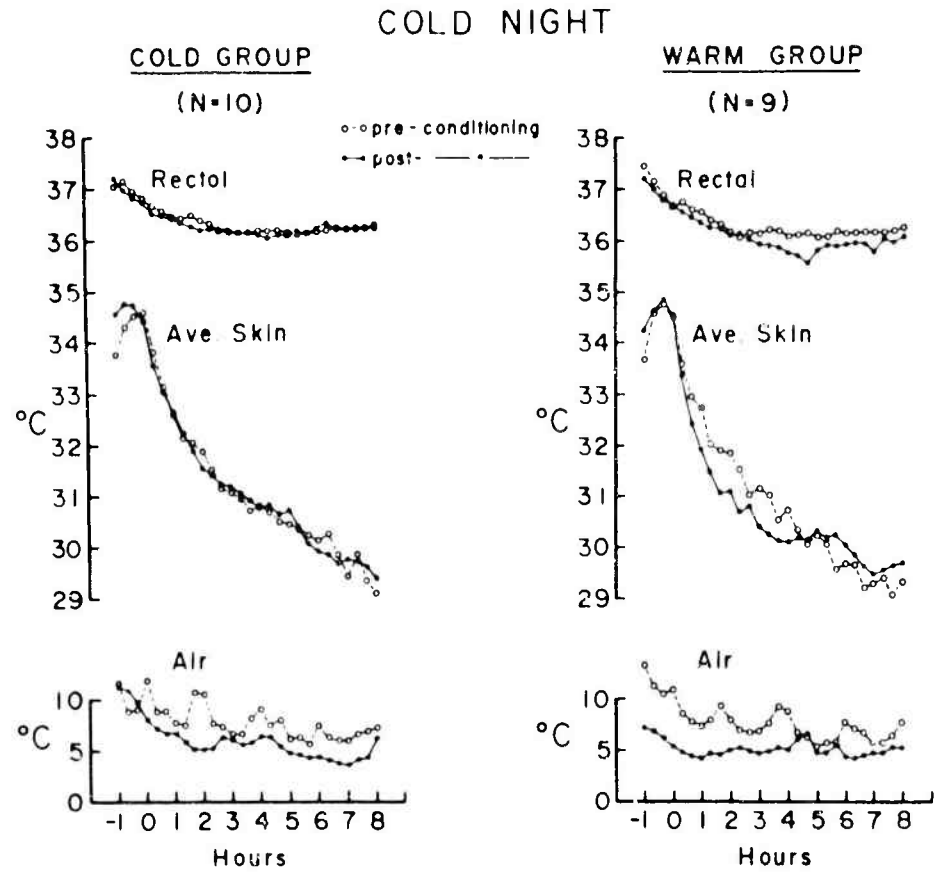


Figure 5.

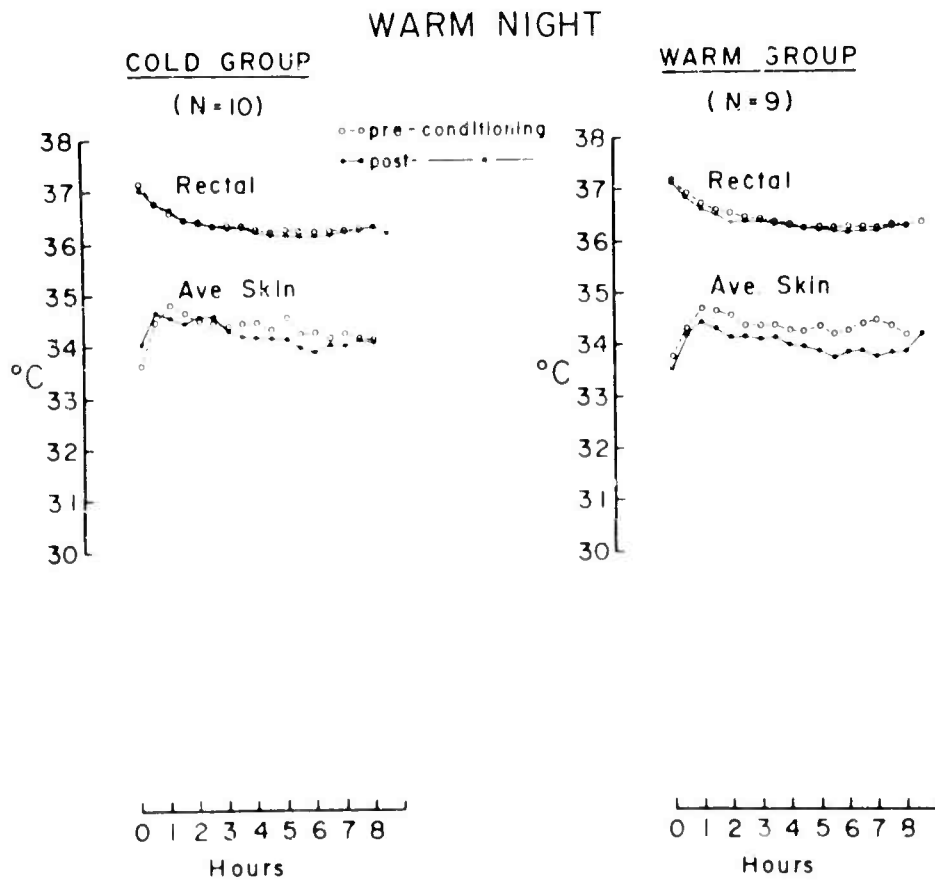


Figure 6.
Foot Temperature

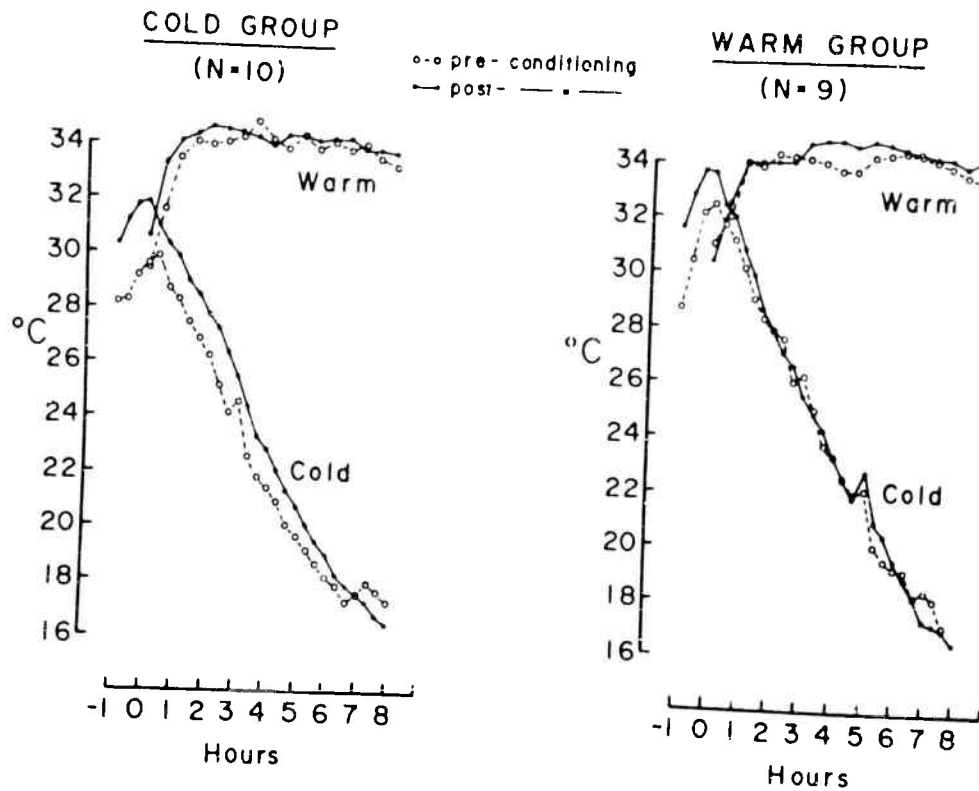
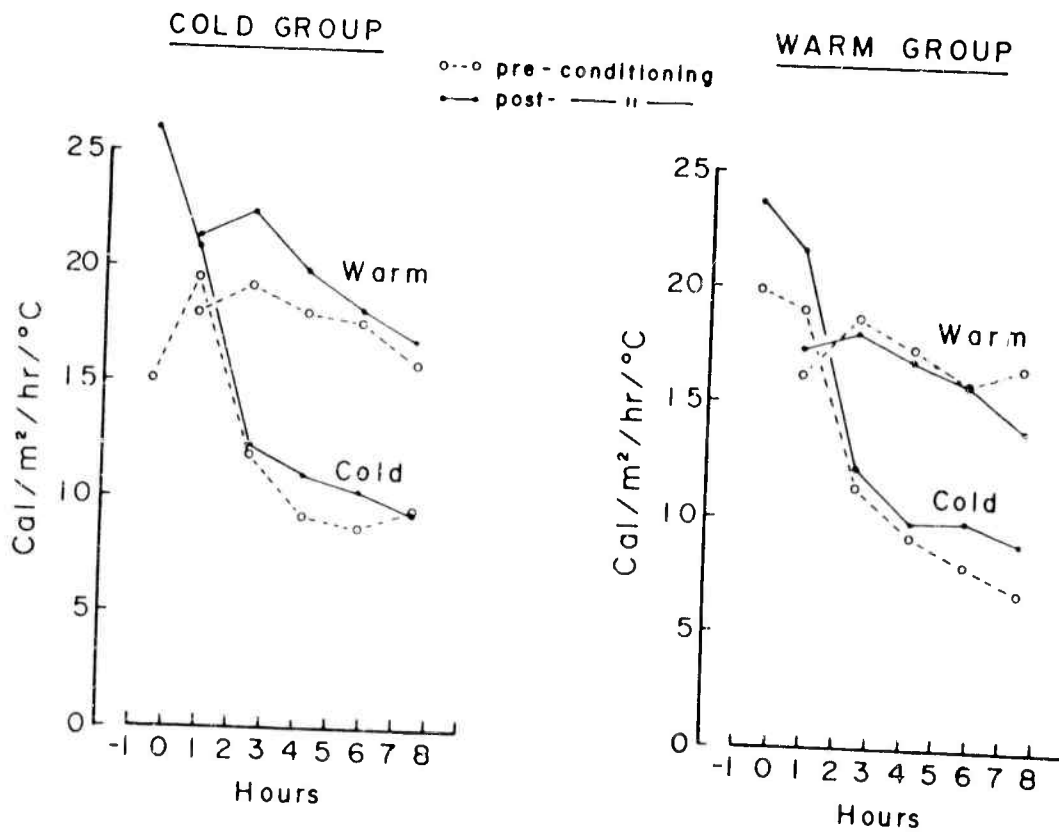


Figure 7.
Tissue Conductance



FIGURES

Figure 1.

Example of a calibration curve obtained nightly for Beckman Model C-2 Oxygen Meter.

Figure 2.

Group average metabolic responses of COLD and WARM Groups throughout warm test nights before and after conditioning.

Figure 3.

Group average metabolic responses of COLD and WARM Groups throughout cold test nights before and after conditioning.

Figure 4.

Group average rectal and weighted average skin temperatures of COLD and WARM Groups throughout cold test nights before and after conditioning.
Average air temperatures within the chamber are also shown.

Figure 5.

Group average rectal and weighted average skin temperatures of COLD and WARM Groups throughout warm test nights before and after conditioning.

Figure 6.

Group average foot temperature of COLD and WARM Groups in cold and warm tests before and after conditioning.

Figure 7.

Group average tissue conductance of COLD and WARM Groups in cold and warm tests before and after conditioning.

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2) Sleep and muscle activity during general body cooling.

Introduction

The use of a night long moderate cold exposure as a test of cold tolerance has been outlined in the general introduction. The ability to rest and sleep is considered to be an important criterion of adaptation to cold since the normal pattern of diurnal activities could not go on for more than a few days without it. Therefore, observations on sleep have been made in this as in some of the previous studies in which subjects were exposed to moderate cold during the usual sleeping hours of the night (1, 2, 3).

In assessing duration and interruptions of sleep, the subject's personal appraisal is poor whereas the electroencephalographic (EEG) pattern of sleep is objective and considered quantitative (4). Therefore it has been used in these experiments and in those mentioned above.

Interruption of sleep in the cold is associated with painfully cold skin and bouts of shivering. Improved ability to sleep may be associated with the ability to ignore or suppress these unpleasant sensations. Suppression of the reaction to cold skin may lead to sleep throughout the night without increased metabolism but to a degree of body cooling (5). However, the ability to rest in spite of an increase of cold induced metabolism, as was reported by Scholander et al. (6), suggests either a more efficient pattern of alternating sleep and shivering, or an increase in cold induced metabolism without a corresponding increase in shivering. The latter mechanism would indicate a change from shivering towards non-shivering thermogenesis. To obtain evidence bearing on these points requires concomitant observations on shivering and metabolism. Therefore, as in the previous studies mentioned above, the electrical activity of the muscles (EMG) was also recorded.

Methods

Sleep and electrical activity of muscle were monitored in each of the 19 subjects throughout five night tests described elsewhere in this monograph - a warm and a cold night during the period of preliminary testing at Oslo, similar warm and cold nights at the end of the training period at Rjukan Fjellstue, and a final observation made under more moderate cold conditions also at the end of the training period.

The EEG record was obtained from a pair of fronto-occipital scalp electrodes and the EMG record from a pair of skin electrodes situated one in each deltoid region. The techniques used were similar to those described in previous reports, but with some modifications. Therefore, the methods are set out in some detail.

Electrodes.

Needle electrodes have been found to be most reliable. These were made from 1/2 inch, 27 gauge hypodermic needles. The hub was cut off near the shaft and the needle soldered to a six-foot length of light-weight, flexible, insulated hook-up wire (No. 28). These electrodes may be autoclaved, but in the field sterilization with alcohol was used although it is recognized that this carried a small risk of virus infection.

The scalp electrodes were placed near the midline, one in the frontal area just at the hair line and one at approximately the same level near theinion. The needle is inserted with a sharp jab almost parallel to the surface so that it traverses the dense corium of the scalp for most of its length and is firmly held. The junction of the needle and the wire is then fixed to the scalp with a drop of collodion. For the EMG, four needle electrodes were inserted subcutaneously, one in each deltoid region and in each femoral region, and held in place with adhesive tape. Insertion of the needles may produce a transient stinging sensation but there is little or no subsequent discomfort. The electrodes were taped to the skin with sufficient slack to allow free movement of the head and limbs.

Surface electrodes fixed only with collodion or tape were not as satisfactory as the needles and therefore were used only as spares. Scalp electrodes of the Montreal Neurological Institute silver cup and pad type (7) were routinely applied in the frontal and occipital regions in addition to the two needle electrodes. The pad was soaked in an electrolyte solution and applied to a small depilated and cleansed area of skin, and fixed there with collodion. The surface electrodes used for muscle pick-up were small silver discs applied to the skin with electrode jelly and held in place with adhesive tape. In the present experiments one of these was routinely applied to the scapular region and used as a ground electrode.

When the electrodes and thermocouples had been applied the subjects were positioned for the night in the sleeping chamber and the electrodes were connected with pin jacks to numbered positions of a junction box

located near the subject's cot. Eight-core multiconductor shielded cable of suitable length (15 to 25 ft) led from the junction box through a port in the sleeping chamber to the recording bench. The shielded cable from two subjects were each plugged into one side of the switch box. When three subjects were being studied during one night only two could be recorded simultaneously. In this case the record from the subject undergoing a warm night test was taken only at hourly intervals.

Switchbox and recorders.

The recorders used were two - 2 channel Gilson Medical Electronics cardioencephalograph machines with paper speeds of 0.25 or 2.5 cm/sec. Usually these machines are wired to record the EEG on one channel and the EKG or EMG on the other. By replacing the EKG amplifier modulo both channels were made identical and capable of recording either EEG or EMG potentials without change in the machine calibration by providing suitable resistances in the EMG circuits in the switchbox. From the input of the switchbox, pin jacks and short connecting wires were used to select any pair of electrodes to be fed into either channel of either recorder. This arrangement allowed for considerable versatility by manipulation of the switchbox - i.e. two EEG channels or two EMG channels from either subject or one from both subjects could be recorded simultaneously on one recorder, or the EMG and EEG could be recorded simultaneously from either subject.

Usual arrangement of recording.

For the EEG records the fast paper speed is required, but it is convenient and economical to record the EMG at the slow paper speed. Therefore, the following arrangement was found most convenient and was used routinely: The fronto-occipital pair of scalp needle electrodes from both subjects were fed into the two channels of one machine (the cup electrodes were used as spares provided the fronto-occipital pairing of electrodes was maintained for each subject). This machine was switched on intermittently to obtain sample tracings of the EEG pattern from both subjects.

The pairs of deltoid electrodes from both subjects were fed into the two channels of the other recorder. The femoral electrodes were kept as spares. The bi-deltoid electrodes recorded a lead II cardiogram from each subject which was recorded at slow speed continuously throughout the night. Electrical muscle activity - shivering or other movements -

were superimposed on these cardiograph tracings. If desired, the pattern could be examined more closely by increasing the paper speed from .25 to 2.5 cm/sec.

Analysis of the records.

EEG - At the start and end of a night's observation each channel was calibrated and the basic alpha pattern was recorded from each subject with the eyes closed. Thereafter throughout the night intermittent tracings were taken for 20 to 40 seconds, every five minutes, giving approximately 100 records from each subject for an eight hour test period. Each of these records was graded from 0 (awake) to 3 (deep sleep) according to standard criteria (4) as illustrated previously (1). From these records the incidence of wakefulness during the night was derived (expressed as per cent of the number of samples) and also the average sleep grade calculated for the night. In addition, the sleep grades were correlated with electrical activity of muscle during the corresponding 5-minute periods.

EMG - The continuous slow speed record was measured off in 5-minute intervals (75 cm). Muscle activity over the background cardiogram tracing for the most part represented shivering but other muscle activity such as limb movements or turning were also registered as electrical activity. The type of record obtained is similar to that illustrated previously (1).

Although the amplitude of the disturbances varied considerably between shivering bouts this was not taken into account in the analysis. For each 5 minutes of recording the length only of the disturbances was recorded and expressed as a per cent of the length of the record. Thus, a semi-quantitative measurement of electrical activity of the shoulder girdle muscles was recorded every 5 minutes throughout the night and could be related to the sleep records and to the oxygen consumption.

The sum of the length of all the electrical disturbances throughout the night related to the total time of recording gave a single mean figure for that experimental period for comparison with other experimental periods for that or other subjects.

Results

Sleep.

Tables I and II summarize the sleep data derived from the EEG records.

In Table I the per cent incidence of wakefulness is recorded. On the average, wakefulness was less after the training period than before, but this trend achieves statistical significance at the 5% level only in the Cold Group for the cold nights.

The same trend towards better sleep after the training period is seen in Table II which shows the average EEG sleep grade for the all-night tests. However, the trend does not reach statistical significance in either group. If both groups are taken together, the increase in average sleep grade during the cold nights between the pre-training and post-training tests is significant. In the moderate cold tests done at the end of the training period the difference between the groups is insignificant.

These results suggest that sleep in the cold may be somewhat improved after the training period, but the evidence is not convincing that Group II (Cold Group) fared any better than Group I who were not cold exposed.

Electrical Muscle Activity.

The nightly mean data are set forth in Table III for both groups of subjects in all five tests. Statistical analysis indicates no significant differences between the two groups of subjects either before or after the training period. However, the data show that the training period induced a change, equally in both groups, in that more shivering occurred during the cold night after the training period compared to the preliminary test.

Relationship Between Sleep and Shivering.

During the warm nights the subjects remained asleep during most of the night with infrequent and brief periods of waking, although the depth of sleep varied frequently. In the cold nights, in all subjects of both groups, sleep was frequently interrupted. The subjects woke up during shivering and whatever sleep they obtained was between shivering bouts. The pattern was the same as that reported in a previous study (2).

Whether the ability to sleep through short periods of light shivering is enhanced by the training period in either group has not been definitely answered in the present experiments since only occasionally and in a random manner were the EEG and EMG recorded together at the exact time of the onset of a bout of shivering. However, the impression gained from those occasional records is that in both groups subjects had a limited ability to sleep throughout a brief and feeble shiver.

Relationship Between Oxygen Consumption and Electrical Activity of Muscle.

We have previously reported that in both "cold adapted" subjects and "non-adapted" controls there is a significant relationship between shivering and oxygen consumption (2, 3). However, the present experiments provide the opportunity to determine whether there is a change in the relationship between shivering and oxygen consumption after a period of physical training with or without additional cold exposure.

Table IV shows the data pertinent to this comparison. The mean electrical activity recorded is tabulated along with the mean oxygen consumption for each cold night for each subject, both before and after the training period. The relationship between these two parameters is indicated by the ratio of one to the other.

Both muscle electrical activity and oxygen consumption are increased by the training period. There is no difference in either of these parameters between the two groups of subjects. The relationship between shivering and oxygen consumption as indicated by the ratio is not affected by the training period.

Therefore these data do not indicate that physical training plus cold exposure leads to a shift from shivering to non-shivering thermogenesis (8).

Discussion

Some limitation must be placed on the interpretation of these results since (a) the shivering data are only semi-quantitative, in that duration of shivering only was measured with no regard to amplitude; and since (b) the shivering data used in the statistical analysis were obtained from bi-deltoid needle electrodes and therefore relate only to the shoulder girdle muscles. However, we know of no evidence to indicate that the rest of the body behaves differently from the shoulder girdle muscles.

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Notwithstanding these reservations, it is felt that certain conclusions may be drawn from these experiments. The data indicate that physical training induced an increase in shivering during the cold night tests. However, no effect of cold exposure in addition to the period of physical training has been demonstrated. The latter statement does not exclude the possibility that cold exposure alone, without physical training, may induce similar or other changes which would be of advantage during a cold night.

The trend towards better sleep after the training period, although not particularly convincing statistically, is in agreement with the subjective assessment of the subjects and with Scholander et al. (6). This trend in the sleep data and the increase in shivering and oxygen consumption indicates the possibility that after the training period the subjects have the same pattern of alternating sleep and shivering as before the training period, but that they achieve somewhat more sleep between somewhat longer bouts of shivering.

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Table II.

Average Sleep Grade¹

	WARM NIGHTS			COLD NIGHTS			MODERATE COLD NIGHT
	Oslo	Rjukan	Mean Difference	Oslo	Rjukan	Mean Difference ²	Rjukan
GROUP I Physical Training Only	1.33 (5)	1.41 (9)	+ 0.06 (5)	0.63 (6)	0.83 (6)	0.17 ± S.E. 0.14 (6) p 0.3	1.12 ± S.E. 0.07 (9) p 0.2
GROUP II Training and Cold Exposure	1.35 (8)	1.63 (6)	+ 0.23 (6)	0.56 (10)	0.85 (8)	0.31 ± S.E. 0.15 (8) p 0.1	1.25 ± S.E. 0.06 (10)

Table III.

Electrical Muscle Activity - Per Cent of Recorded Time

	WARM NIGHTS			COLD NIGHTS			MODERATE COLD NIGHT
	Oslo	Rjukan	Mean Difference	Oslo	Rjukan	Mean Difference	Rjukan
GROUP I Physical Training Only	29.7 (8)	1.84 (8)	1.31 \pm S.E.	8.34 (9)	14.12 (9)	5.79* \pm S.E.	3.98 \pm S.E.
			p 0.4			p .05	0.55 (9)
GROUP II Training and Cold Exposure	1.17 (8)	1.38 (8)	0.3 \pm S.E.	6.53 (10)	8.62 (10)	2.08* \pm S.E.	4.10 \pm S.E.
			p 0.6			p.C.02	0.75 (10)

Table IV.

Relationship Between Shivering and Heat Production During Cold Night Tests

PRELIMINARY TESTS (OSLO)

POST TRAINING TEST (RJUKAN)

Subject	Shivering % of time	Heat Production cal/kg/hr	Ratio Shivering: Heat Production	Shivering % of time	Heat Production cal/kg/hr	Ratio Shivering: Heat Production	$R_1 - R_2$
GROUP I: Physical Training Only							
1	10.53	1.30	8.10	17.37	1.51	11.50	- 3.4
2	18.22	1.21	15.06	8.71	1.46	5.97	+ 9.1
3	6.26	1.21	5.17	20.61	1.52	13.56	- 8.4
4	7.51	1.49	5.04	16.98	1.63	10.41	- 5.4
5	4.23	1.21	3.50	6.70	1.32	5.08	- 1.6
6	9.04	1.20	7.53	11.19	1.64	6.82	+ 0.7
7	7.80	1.46	5.34	10.78	1.60	6.74	- 1.4
8	5.89	1.11	5.31	14.12	1.54	9.17	- 3.9
9	9.73	1.47	6.62	20.68	1.46	14.16	- 7.5
							- 2.42 ± S.E. 1.74
							p = 0.2
GROUP II: Training and Cold Exposure							
1	8.0	1.46	5.48	12.1	1.67	7.25	- 1.7
2	12.31	1.54	7.99	14.37	1.87	7.68	+ 0.3
3	8.49	1.47	5.78	7.48	1.66	4.51	+ 1.3
4	3.32	1.03	3.22	5.31	1.37	3.88	- 0.7
5	1.10	1.20	.92	4.71	1.47	3.20	- 2.3
6	7.23	1.39	5.20	13.72	1.58	8.68	- 3.5
7	4.15	1.33	3.12	4.61	1.39	3.32	- 0.2
8	3.26	1.25	2.61	2.63	1.3	2.02	+ 0.6
9	9.04	1.30	6.95	11.25	1.72	6.54	+ 0.4
10	8.45	1.39	6.08	10.00	1.33	7.52	- 1.4
							- 0.72 ± S.E. 0.47
							p = 0.2

Legend to Table I

¹ Per cent incidence of wakefulness is taken as the number of EEG sample records for each subject which shows an "awake" pattern expressed as a percentage of the total number of samples recorded in the period under consideration. All records for the whole night were used in calculating the figures for the "warm nights" and the "moderate cold nights". In the "cold nights" the records of the first warm hour preceding the cold hours are excluded.

² The numbers in brackets indicate the number of subjects contributing to the mean. Satisfactory sleep records were not obtained in all tests for technical reasons and also because during most "warm night" tests, two other subjects undergoing "cold nights" were given preference on the available recording channels.

³ For the warm and cold night tests the data were subjected to paired data analysis. The moderate cold night test was only done once on each subject and in this case the "t" test for the difference between means was applied.

The values achieving a statistical probability of 0.05 or less in this and subsequent tables are marked with an asterisk.

Legend to Table II

¹ The average sleep grade was calculated for the whole of each night (except for the first warm hour of the cold night tests), although it is recognized that the grades of sleep are not strictly quantitatively related one to the other.

² If all subjects are considered together the improvement in sleep grade for the cold nights between pre- and post-training tests reaches a statistical probability of 0.05.

Legend to Table III

See Legend to Table I.

3) Aspects on peripheral circulation

Introduction

As discussed in detail in the general introduction there is good evidence to show that warmer extremities in the cold can be a result of cold acclimatization (4, 6, 8, 17, 20, 21), though negative reports exist (3, 12, 14), and though an increase of peripheral vasoconstriction has been reported as developing during chronic cold exposure (7, 9).

It has been suggested that these changes found in the reaction of the peripheral circulation to cold have been a result of physical training rather than an effect of acclimatization to cold (12, 15), but this concept does not, at present time, rest on firm experimental evidence although some suggestive data exist (2). Since many studies of acclimatization to cold include changes in physical fitness, the present experiments were undertaken to try and separate these factors.

The main emphasis was placed upon the finger blood circulation which was studied by venous occlusion plethysmography and skin temperature measurements. However, as finger and toe vasoconstriction may differ in response to a certain cold stress in subjects repeatedly exposed to cold (23), toe temperatures were also measured.

In addition to the abovementioned parameters rectal temperature, average skin surface temperature and oxygen consumption were measured.

The experiments were made before and after the program of physical training and cold exposure. They involved a standard whole body exposure to cold. Towards the end of this period, a local cold exposure of hand and forearm with subsequent local rewarming was added.

Methods

Subjects.

The experimental subjects were the same groups as those described above, and included subject H. B. whose peripheral vasomotor reaction did not differ from the others. Nine of the nineteen subjects were moderate smokers, six of which belonged to the "warm" group.

Procedures

General plan of experiments.

The experimental subjects were studied in a thermostatically controlled climatic chamber at the Institute of Aviation Medicine, Oslo, just before (series I, "pre-exposure") and immediately after (series II, "post-exposure") the five weeks training and acclimatization period at Hardangervidda.

Preparation of subjects.

Considerable care was taken to keep the experimental subjects under the best possible standardized conditions. They were therefore studied from the morning, fasting after a good night's sleep. No exposure to uncomfortable temperature, physical exertion or smoking had taken place before the subject entered the laboratory at 8.30 a.m. In series II, it was necessary to study two subjects in each group in the afternoon (from 1.30 p.m.) after they had eaten a light meal of low protein content in the morning. The data did not indicate that this modification of procedure substantially altered the subjects' response to the applied cold stress.

Environmental conditions and time schedules.

The experimental subjects were studied naked except for cotton shorts. They were throughout the experimental period resting in the supine position on a bed with a wire mesh bottom which was covered by a single blanket. Care was taken to obtain a calm and reassuring atmosphere in the laboratory during the experiment.

The experiment lasted for four hours, and from the time the subject entered the climatic chamber at zero time, it consisted of the following consecutive phases:

- (a) Comfortable warm period (0 to 80 min.). The warm environment was characterized by an air temperature of 30° - 32° C, wall temperature within the same range, air velocity below 10 cm per second and relative humidity (which could not be controlled) in the range 35 to 55 %. During the first hour of this period the apparatuses were attached to the subject. Recordings were started 20 minutes before change of environmental temperature.

(b) Decreasing environmental temperature (80 to 95 min.).

During this phase of the experiment, ambient air temperature was gradually lowered to about 19°C , without change in air movement.

(c) General moderate cold exposure (95 to 180 min.).

Air temperature was maintained at $19^{\circ} \pm 1.3^{\circ}\text{C}$, continuously fluctuating within this range. Air movement and relative humidity were within the same ranges as mentioned for the warm environment, whereas the wall temperature slowly dropped to approach air temperature.

(d) Combined general and local cold exposure (180 to 210 min.).

No changes were undertaken in the general environment during this phase of the experiment, but the subject rested his left hand and forearm in a cooling-box at an air temperature of $+5^{\circ} \pm 0.3^{\circ}\text{C}$, air speed about 25 cm/second and wall temperature within range of air temperature.

(e) Local re-warming (210 to 240 min.). The hand and forearm were withdrawn from the cooling-box, and allowed to re-warm in ambient conditions as in (c).

Measurements

Finger blood flow.

Finger blood flow was measured indirectly in the distal two phalanges of the second finger, left hand, by venous occlusion plethysmography. The apparatus was of the airfilled type, and both instrumentation and procedure has been described in detail elsewhere (13). Series of three to five inflow recordings, from which the average blood flow was calculated, were obtained in rapid succession each tenth minute throughout the experimental period.

Measurement of finger volume was by water displacement (accuracy within $\pm 2\%$), and in "series II" an equally large part of the finger, as studied in "series I", was placed in the plethysmographic cup so that no change in finger volume might cause differences in blood flow values between the two experimental series.

Intracutaneous finger temperature.

The intracutaneous skin temperature was measured by a 36 gauge B. & S. copper constantan thermocouple inserted into the superficial layer

of the skin in the midline of the dorsal aspect of the distal phalanx of the third finger, left hand. The tunnel into which the thermocouple was inserted was about 1 cm long, parallel to the surface and so superficially situated in the epidermis that no blood was drawn when it was prepared (which was done with the aid of a thin sewing needle). Care was taken to secure complete covering of the proximal part of the thermojunction by epidermis, and the wires were fixed to the skin proximally by a piece of adhesive tape. The temperatures were read on a portable Leeds & Northrup millivolt potentiometer (type 8686), the reference junction being kept in melting ice in a Thermos flask. Accuracy was within $\pm 0.1^{\circ}\text{C}$. Readings were taken every 10 minutes for the first three hours, and every 2 minutes during the last hour, when rapid changes in temperature took place.

Skin surface temperatures.

Skin surface temperatures were recorded by iron/constantan thermocouples attached to the skin by single layers of adhesive tapes (Norges-plaster). The thermocouples were connected to a twelve channel Hartmann and Braun "Polycomp" recorder with inbuilt electrically heated, thermostatically controlled, temperature reference at $+ 50^{\circ}\text{C}$. Accuracy was within $\pm 0.5^{\circ}\text{C}$.

Finger skin surface temperature was measured from the pad of the fourth finger, left hand. Because of the plethysmographic recordings from the same hand, the position of the finger was throughout the experiment about 10 cm above the heart level.

Toe temperatures were recorded from the pad of each big toe, the mean of both readings were taken as average toe temperature.

Average skin surface temperature was measured as described by Hammel *et al.* (11), by calculation of a weighted mean of measurements from the following eight points (factors in parentheses): 1) forehead (0.07), 2) dorsum of right hand (0.05), 3) lateral side of upper arm (0.14), 4) pectoral region (0.18), 5) scapula (0.17), 6) lateral side of thigh (0.19), 7) lower leg (0.13), 8) dorsum of foot (0.07). Due to the relatively slow response of this derived parameter upon changes in environmental temperature, calculations were undertaken only from each tenth set of temperature recordings, corresponding to each eighth minute.

Rectal temperature.

Rectal temperature were measured by a thick (28 gauge B. & S.) copper/constantan thermocouple melted into a thin plastic tube, the tip of which was inserted 10 to 12 cm inside the anus. Measurements were otherwise undertaken by instruments identical to those used for the study of intracutaneous temperature.

Oxygen consumption.

Oxygen consumption was measured during a 10 minute sampling period toward the end of the general warm period, and in the course of a sampling period of equal duration after one hour's exposure to mild cold. The conventional respiration valve/Douglas bag technique was used. The air was inspired through a wide hose the rear end of which was situated outside the laboratory building. The volume of the expired gas was measured by a dry gas meter, and its contents of O₂ and CO₂ measured by using Scho-lander's $\frac{1}{2}$ cc gas analyzer.

Statistical methods

Only current statistical methods were applied. As the subjects served as their own controls, estimation of statistical significance of differences between means of the corresponding parameters in series II vs. series I was by the t-test for paired data. The statistical significance of differences between means in different groups was estimated by the conventional t-test.

Results

As indicated by the results shown in table I, the smokers did not differ systematically from the non-smokers in the reaction of the peripheral circulation to the experimental cold exposure. In the warm environment there was a statistically insignificant tendency toward a more marked peripheral vasodilatation in the smokers. In the following presentation no distinction is made between the results of smokers and non-smokers within each group.

TABLE I.

Finger blood flow and finger- and toe skin temperatures in smokers vs. non-smokers in series I. Mean \pm S.E. Measurements at the end of the warm resp. cold exposure.

GROUP (N)	Blood flow (ml/min/100 ml tissue)		Finger Temp. ($^{\circ}$ C)		Toe Temp. ($^{\circ}$ C)	
	Warm ^{x)}	Cold	Warm	Cold	Warm	Cold
Smokers (9)	31.6 \pm 6.7	1.4 \pm 0.3	35.4 \pm 0.2	17.0 \pm 0.2	31.4 \pm 0.8	18.5 \pm 0.3
Non-smokers (10)	18.0 \pm 2.9	0.9 \pm 0.1	33.8 \pm 0.6	16.5 \pm 0.1	30.3 \pm 0.8	18.8 \pm 0.2

x) Mean of all measurements in the warm environment.

Finger blood flow.

The plethysmographic results are presented in figures 1 and 2.

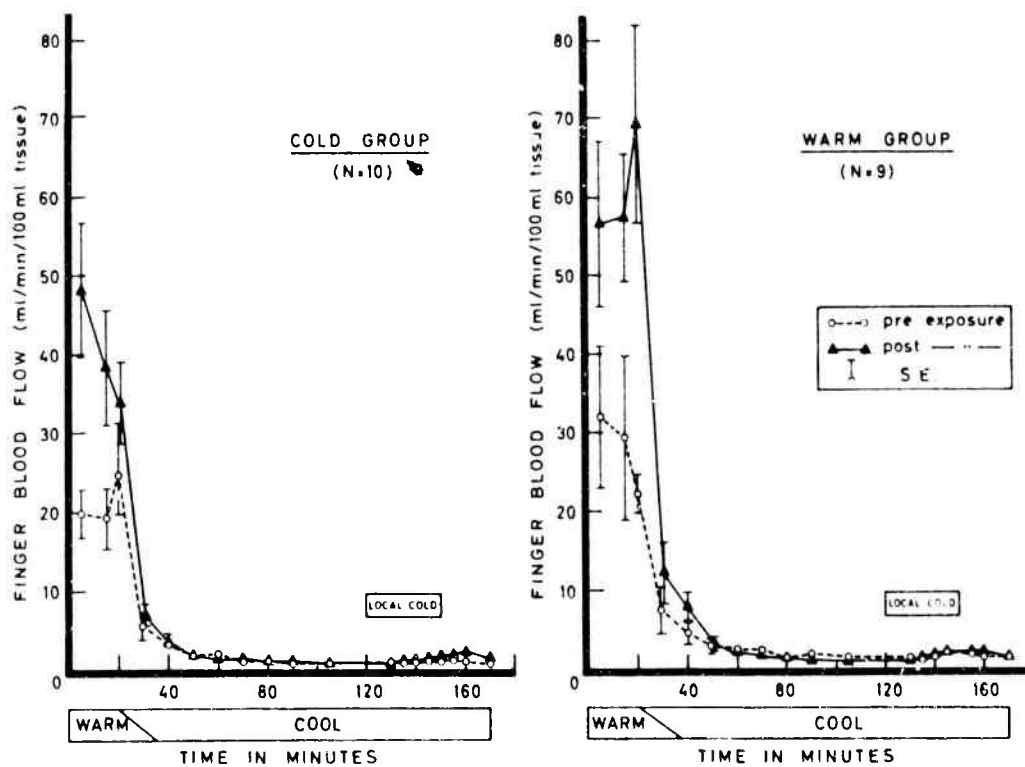


Fig. 1. Finger blood flow in standardized environments before and after the training period. Standard errors are given only for the first part of the experiment (cf. fig. 2).

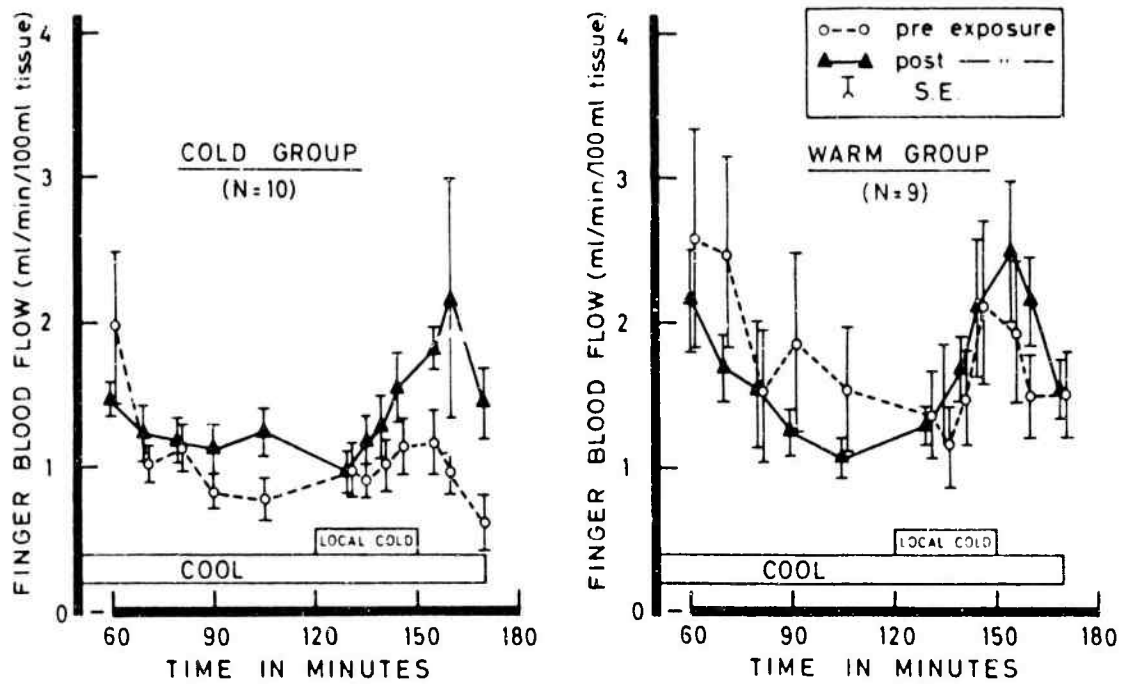


Fig. 2. Finger blood flow during standardized general (19°C) and local (5°C) cold exposure before and after the training period.

In the comfortably warm environment, finger blood flow values fluctuated considerably in most subjects, and marked interindividual variations were also found.

Though a very wide range -- from below 10 to above 100 ml/min/100 ml tissue was covered by the blood flow values in the warm environment, there was in both groups a marked tendency toward an increased finger blood flow in this comfortable environment from the first to the second experimental series.

The mean finger blood flow in the warm environment was in both groups probably significantly higher in series II than in series I (0.02 p 0.05). There was found no statistically significant correlation between finger blood flow in the warm environment and resting oxygen consumption (total or related to body weight), nor were blood flow values in the warm environment significantly correlated to maximal oxygen uptake (as measured by other workers, cf. chapter). Lack of significant correlation was also found between the increase in mean warm finger blood flow from series I to series II, and the increase in the respective abovementioned parameters.

Considerable reduction of finger blood flow was a prompt response to the lowering of ambient air temperature in all subjects, so that even before the 19°C level of ambient air temperature was reached, marked reduction of blood flow was a fact (cf. fig. 1). During the whole period of general cold exposure, finger blood flow stayed at low values in the range 0.5 to about 2.0 ml/min/100 ml tissue. No difference in the reaction of finger blood flow to the general cold stress was found between series I and II in either group (fig. 2).

The addition of a local cold exposure did not substantially influence the finger blood flow values which were already stabilized at minimal or near minimal levels. The trend during local cold exposure was in fact rather towards a slight increase in finger blood flow than towards stronger vasoconstriction, but no marked coldinduced vasodilatation was found in any subject.

During the re-warming period after local cold exposure, finger blood flow values also remained at a fairly low level, and no significant difference was present between the results of the two experimental series. The only exception to this general finding was a significantly (p 0.02) higher blood flow in the very last measurement in the cold group in series II as compared with series I.

Intracutaneous finger temperature.

The results of the intracutaneous skin temperature measurements are shown in fig. 3.

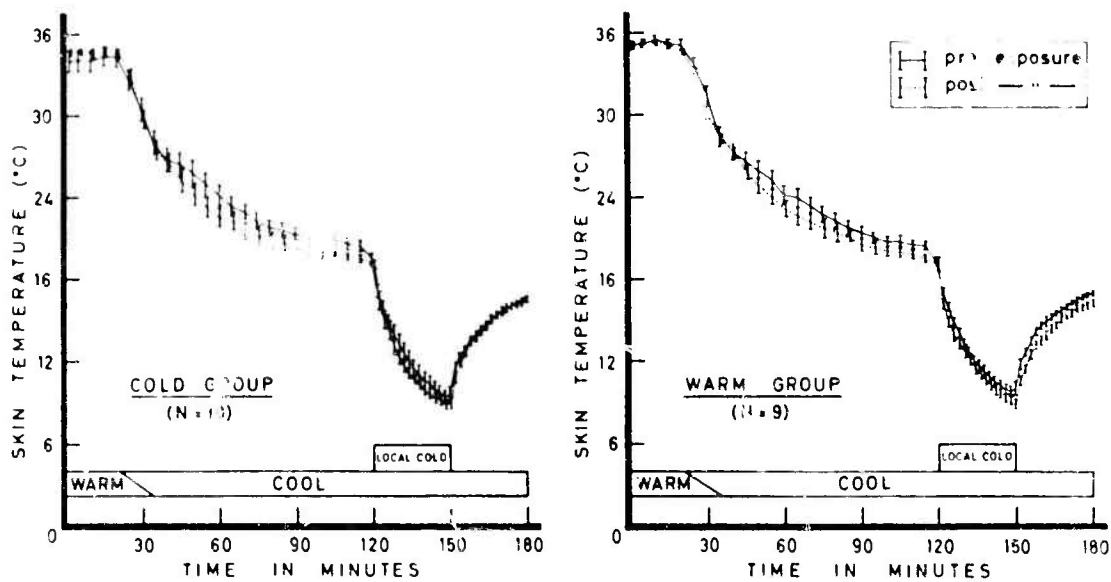


Fig. 3. Intracutaneous temperature measured in the epidermis of the dorsal aspect of the distal phalanx of the third finger during exposure to standardised environments. Vertical lines denote \pm S.E.

As shown in fig. 3, the skin temperature started out at fairly high levels (34° - 35°C) in the warm environment and immediately began to decrease upon lowering of ambient air temperature. This decreasing response was much slower than for local blood flow (cp. figs. 1 and 3), and flattening out at near ambient air temperature level was not obtained until about one hour after the onset of temperature decrease.

In the course of the whole experimental period - with the possible exception of a slight and not statistically significant trend toward higher temperatures in the warm environment in series II in the cold group - no evidence in favour of warmer fingers in series II was found. On the contrary, there was on the average a modest tendency toward quicker finger cooling to lower temperatures in series II than in series I in both groups.

Skin surface temperatures.

Finger skin surface temperature. The results of the finger skin surface temperature recordings differed little from those measured intracutaneously on the adjacent finger, and the trends of the results were in the same direction as for those given in fig. 3.

Toe skin surface temperature. Toe temperatures are shown in figure 4. In the cold group the mean toe temperature was statistically higher ($p = 0.01$) in series II than in series I throughout the experiment. The difference was most marked in the warm environment, and the rates of cooling were comparable between the two series.

In the warm group the same tendency is seen although here the differences in toe temperature between series I and series II do not achieve statistical significance.

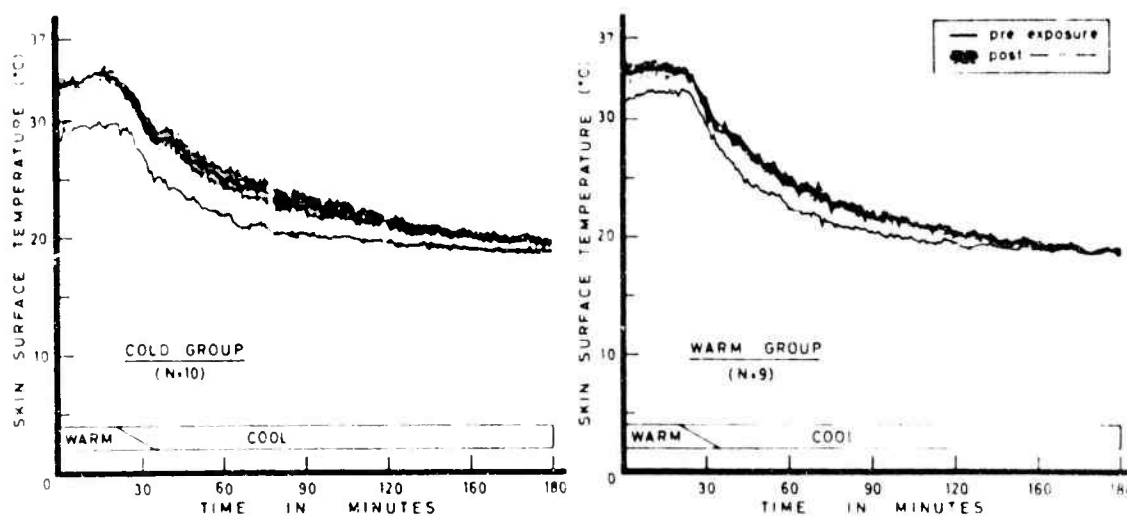


Fig. 4. Toe temperatures during exposure to the standardized environments before and after the training period. The values shown in the figure are means of skin surface temperatures recorded from the pads of both big toes. The curves give mean values \pm S.E.

Average skin temperature. The mean values and standard errors are shown in figure 5.

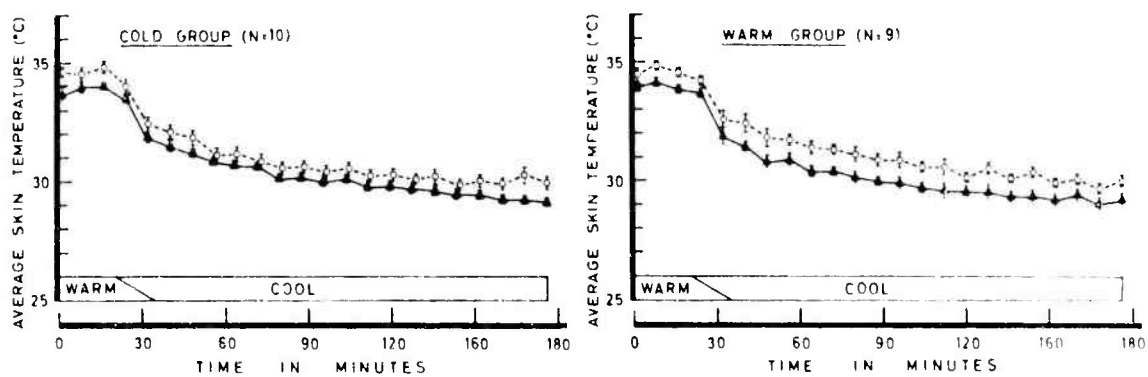


Fig. 5. Average skin surface temperature in standardized environments before and after the training period. Triangles: pre-exposure. Circles: post-exposure. Vertical lines mark \pm S.E.

In the warm period the average skin temperature was approximately 34°C in both groups. On cold exposure this fell gradually by about 5° . In both groups the mean skin temperature was higher in series II than in series I throughout the test. This was most marked in the warm group.

Rectal temperatures.

The rectal temperatures are presented in fig. 6.

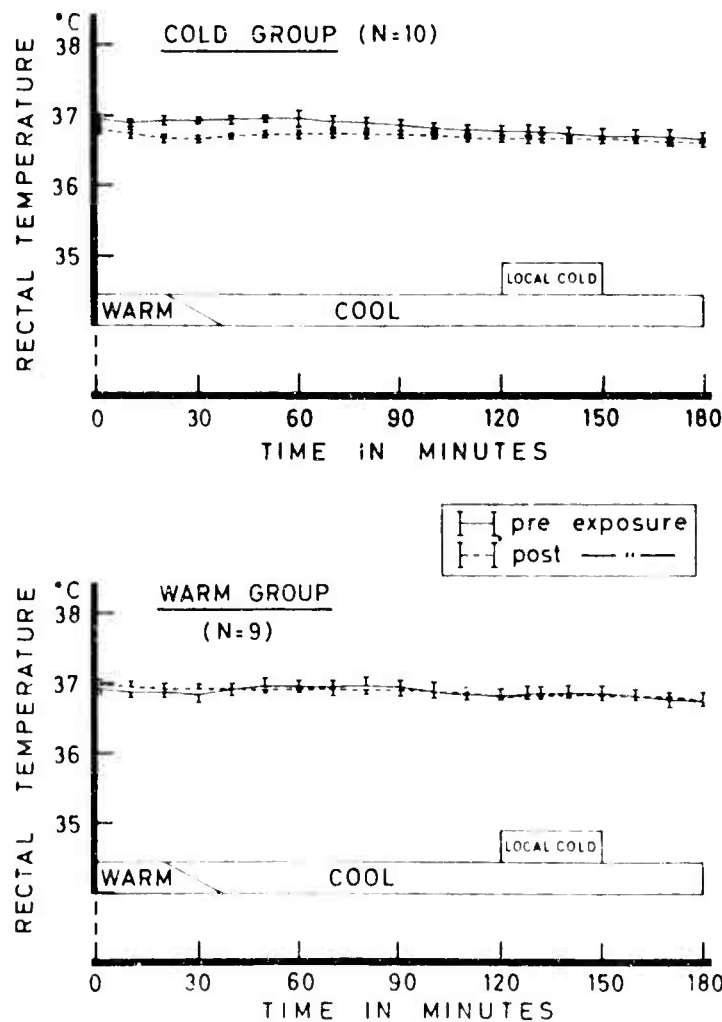


Fig. 6. Rectal temperatures. Vertical lines denote \pm S.E.

There was on average a drop in rectal temperature of about a quarter of one degree centigrade in the course of the experiment. Practically no difference was present between rectal temperatures of series I and II in the warm group, whereas this indicator of core temperature tended to be lower during the first third of the experiment in the cold group. The mean difference was on its maximum during the second half hour of the experiment, when it was of a magnitude of 0.3°C and statistically significant ($p = 0.01$).

Oxygen consumption.

Due to technical failure it was not obtained complete results in the measurements of oxygen consumption. In Table 2 are given the results for the 14 subjects for whom a complete set of four measurements were achieved.

There was on the average a trend towards a slight increase of oxygen consumption at general cold exposure. In these small groups the increase was however not statistically significant. A trend towards increase of resting metabolism in the warm environment from the first to the second experimental series was present in the warm group, but not in the mean values of the fraction of the cold group in which the data were complete.

Subjective discomfort.

In the warm environment the subjects felt comfortable and no visible sweating was observed.

No attempt was made to quantitate discomfort during the cold exposure. However, there were some relatively minor complaints of cold, stiffness from maintaining one position for long periods, and boredom. All subjects shivered towards the end of the cold exposure. These complaints were generally less from both groups in series II compared with series I. It is interesting that the cold group regarded this test situation as being colder than their nightly cold exposure during the training period.

Table 2.

Oxygen consumption (STPD) in standard warm and cool environment. Mean values \pm S.E.

GROUP (N)	Pre-exposure			Post-exposure		
	ml/min/kg	body weight	Increase ^{x)} (per cent)	ml/min/kg	body weight	Increase ^{x)} (per cent)
	Warm	Cool		Warm	Cool	
Warm (6)	3.7 \pm 0.18	4.4 \pm 0.45	18 \pm 8.4	4.0 \pm 0.25	4.3 \pm 0.16	8 \pm 6.7
Cold (7)	3.7 \pm 0.20	4.0 \pm 0.18	12 \pm 6.1	3.5 \pm 0.08	3.8 \pm 0.10	8 \pm 4.4

^{x)} Increase in oxygen consumption from warm to cool environment.

Discussion

Finger blood flow.

It is rather surprising that the only difference in finger blood flow between series I and series II was found in the warm environment. As this increase in blood flow was of about the same magnitude in both groups, it cannot be attributed to the cold exposure. It seems most probable that it may be related to the increase in heat production under resting warm conditions shown in both groups in another study (cf. chapter). The lack of a significant correlation between the blood flow and oxygen consumption data does not strengthen this assumption, but the measurements of oxygen uptake were incomplete and obtained during a rather short period of time.

Under environmental conditions comparable to those applied in the first part of the experiment, blood flow in the fingers continuously fluctuates within wide ranges (5) and is particularly apt to be influenced by a variety of external and internal stimuli including emotional ones (1, 16). Although the experimental conditions were standardized, it is most possible that the subjects viewed their first experience with more concern than the second. Emotional factors may thus offer another possible explanation of the differences found in blood flow.

Finger and toe temperatures.

As with the blood flows, the finger temperatures gave no evidence of acclimatization to cold. In view of the increased blood flow in the warm environment in series II, higher skin temperatures might have been expected here. The reason for the failure to show this may be the fact that finger skin temperature is no sensitive index of blood flow when skin temperature, core temperature and air temperature are all close to each other.

The toe temperatures in the warm environment, however, showed an increase from series I to series II which corresponds better with the plethysmographic findings on the fingers. The more marked increase in toe temperature from series I to series II in the cold group as compared with the warm group, is related to a difference between the groups in series I. In series II the mean of toe temperatures in the warm environment was practically identical for the two groups. It seems therefore to be dubious if the more marked increase in toe temperature in the cold group was an effect of the repeated cold exposure during the training period.

The higher toe temperatures in the warm environment in series II indicate an increased blood flow, but the persistence of a temperature difference in the cold environment - most prominent in the cold group - may merely be a physical reflection of the higher initial temperatures. The considerable lag between temperature changes and blood flow changes is well known and is also evident from the results in the finger (cp. fig. 1 and fig. 3). The absence of an increase in the rate of cooling of the toes as a reflex response to the local cold exposure of the hand and forearm, indicates that the toe blood flow at this phase of the experiment was at a low level also in series II in both groups. Unfortunately these points can only be definitely answered by having blood flow measurements of the toes, and these measurements were not made.

Average skin and rectal temperatures.

The general thermal state of the body as indicated by these measurements suggest that the maintenance of higher skin temperatures in the cold in series II possibly reflects an increase in heat production, particularly in the warm group where the differences in average skin temperature were most marked, and where rectal temperatures were practically identical in the two series.

In the cold group, however, there was a significantly lower rectal temperature during the first hour of cooling in series II as compared to series I. This may suggest that this group, after training, were more tolerant of heat loss from the body. To assess this quantitatively in short term experiments is however difficult, particularly since no detailed quantitative measurements of the metabolic response to cold were made during this period.

Experimental conditions.

As no striking differences in the peripheral vasomotoric responses to cold were demonstrated between series I and series II in either group, one might question whether the experimental conditions were the proper ones to demonstrate any differences if they existed. There is little doubt that either a too mild cold stress or a too intense general cooling may obscure differences between acclimatized and non-acclimatized subjects. In the present experiments the general cold exposure was less intense than what most workers have used in experiments which have shown differences in peripheral vasomotoric reaction to cold between acclimatized and non-

acclimatized subjects. In the present experiments the general cold exposure was less intense than what most workers have used in experiments which have shown differences in peripheral vasomotoric reaction to cold between acclimatized and non-acclimatized subjects. Exposure to the 19°C air temperature in our study caused, however, a marked vasoconstriction in all subjects. On the other hand, experiments on healthy young men recently carried out at 25°C air temperature in our laboratory showed such small changes in peripheral temperature that differences between groups might be equally difficult to detect. Observations over a range of ambient air temperatures, as carried out by Wyndham (22, 23), may be necessary to pick up differences between groups or to indicate with more assurance than we have from the present experiments that differences do not exist between the groups tested.

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The impression we gain from the present experiments is that the changes in peripheral circulation we have seen, are related to the physical training and not to cold exposure. The exact nature of the regulatory mechanisms involved in these circulatory alterations do not seem clear.

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4) Pressor responses to cold water immersion of the hand

Introduction

The rise in systolic and diastolic blood pressure found when an appendage is exposed to severe cooling, such as immersion in cold water, has been known for some time. This reaction forms the basis of the "cold pressor test", which was originally introduced by Hines and Brown (9) as a means of detecting potential hypertensives, and more recently there has been considerable interest in this response as the basis of a test for the evaluation of cold acclimatization or habituation.

The mechanism involved in a cold pressor response is still not fully understood. Hines and Brown (9) considered it to be a reflex phenomenon elicited through stimulation of sensory nerves by cold. Other investigators point towards a more complex mechanism, as a close relationship between the subjective experience of pain and pressor reactions has been observed (2, 3, 10). Wolfe and Hardy (14) by selective partial block of nerve trunks concluded that the afferent limb of the pressor response was mediated by small non-myelinated class C fibres. These authors consider the pressor effect to be related to the subjects' reaction to the pain and not directly related to the pain itself. Wolfe (15) reported from studies on patients with a variety of central nervous system lesions that the response is not the result of an infrathalamic reflex, as it occurred only in response to a conscious awareness of pain, and therefore the cold pressor test may be considered to be a measure of sensitivity to a standard painful stimulus rather than a test of vascular reactivity. On the other hand Sherrington (11) and others have found in animals that noxious stimuli may cause a pressor response in decerebrate and spinal animals, and Glaser and Whittow (4) did not find a perfect correlation between pain experienced and the pressor response in that with repeated exposures the sensation of pain did not decrease at the same rate as did the pressor response.

On repeated severe appendage cooling a reduction in the pressor reaction and pain sensation is generally observed (5, 12, 13, 16). Glaser and Whittow (4) studies this process by exposing the hand to 4°C water for 60 seconds at minute intervals and noted a decreased pressor response and decreased pain after six to ten immersions. Repetition of this procedure several days in succession resulted in a gradually reduced response, indicating a retention of adaptation from day to day, which they found was

specific for the hand tested. Finding no evidence of local change in the hand, the authors explained the phenomenon as one of habituation, based on storage of information within the central nervous system. These and other investigators have studied the habituation phenomenon in man and animals with particular reference to its site within the central nervous system. Glaser and Griffin (6) have found the frontal areas of the cerebral cortex to be of importance to cold habituation in the rat, and Griffin (7) has given evidence that these structures are involved also in cold habituation in man. Hernandez - Peon and Brust - Carmon (8) have shown that the process of habituation may also take place at lower levels in the nervous system in animals, even at the spinal level.

From this brief review of the literature it seems that the mechanism for the cold pressor response and of the habituation process are still obscure. However, it may still be possible to use this response imperically to detect and assess cold adaptation.

The reasons for including the cold pressor test in the present investigation.

Since the blood pressor reaction is related to the sensation of pain and discomfort associated with severe cooling, the use of this objective test may be a possible way of quantitating the general tolerance to cold. Therefore, it was included in this study of cold acclimatization.

Knowing the effect of prolonged physical training upon the body functions, there may be little reasons to expect that a training regimen should influence the cold pressor response. But since evidence is brought forth showing that training may reduce vasoconstriction induced by body cooling in the peripheral parts of the body (1) it could be that the mechanism underlying this effect is also working during severe appendage cooling.

The questions asked were:

- 1) Does intermittent moderate general body cooling affect the pressor reaction to severe appendage cooling?
- 2) Does physical conditioning effect the pressor reaction to severe appendage cooling?

Methods

A. Subjects.

The subjects were eighteen healthy men, aged between 19 and 22 years, belonging to the Norwegian Civil Labour Service, who volunteered for the project. The subjects were divided into two equal matched groups as described in chapter I. The general schedule of the main project and the handling of the subjects is also described in chapter I.

The cold pressor tests were performed at the Institute in Oslo before and after the general cold exposure and physical training at Rjukan while the subjects lived at the Institute.

B. Instrumentation.

The cold pressor test requires accurate and objective recording of the systolic and diastolic blood pressure. Furthermore, the measurements must be taken so that the disturbance associated with the test is minimized. This can best be achieved by having the subjects alone in one room, shielded from noise and other disturbances from the surroundings, the measurements being taken and recorded in another room.

In order to obtain such optimal experimental conditions, it was necessary to improve the usual clinical method of measuring blood pressure.

The measurements were based upon the auscultatory method with certain improvements of the technique. An usual brachial cuff was used. Pressure to the cuff was provided from a pressure source. The cuff was inflated by opening an electromagnetic valve, and pressure released by a manually operated needle valve. A microphone was placed on the brachial artery, and the sound signals fed into an amplifier connected to a loudspeaker or earphones. With this equipment blood pressure could be measured in the usual way. A further improvement of this system was the introduction of a pressure transducer on a strain gauge basis into the pressure system feeding into a pre-amplifier and finally into a two-channel pen writer. Likewise the sound was led through a pre-amplifier and into the other channel of the recorder, and the artery sounds recorded on the paper. In this manner the blood pressure could be recorded quite objectively. Figure I shows an example of the recordings obtained.

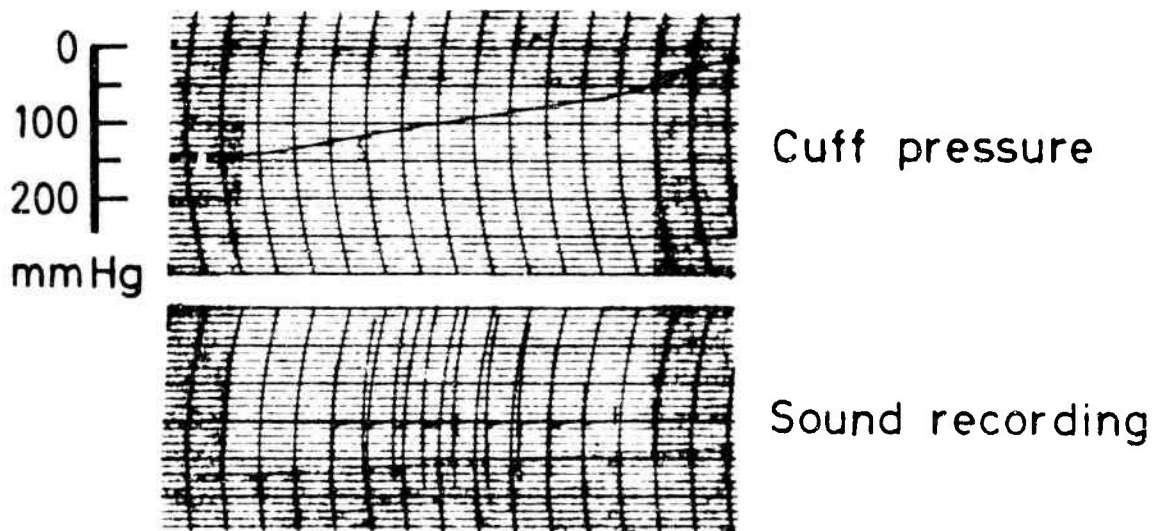


Fig. 1 An example of blood pressure recording.

Heart rate was recorded by means of a standard Mingograph. Skin temperature was automatically recorded by means of copper/constantan thermocouples connected to a Honeywell writer. The cold stimulus was provided by ice water in a thermo-isolated container of about 3 liters capacity.

C. Procedure.

The procedure and the test were the same before and after the experimental period. Tests I and II were identical, performed at the same time of the day on two different days, and consisting of six exposures of the left hand to ice water. Each exposure lasted one minute. with intervals

of one minute in between the exposures. Test III consisted of one exposure of two minutes duration of the right hand. In all experiments the hand was immersed in ice water up to the styloide process.

For all experiments there was a pre-period of one hour with the subjects lying in bed comfortably covered. Then the subjects were taken to the experimental room where they were comfortably seated in an easy chair. A second pre-period of 25 minutes now followed in which measurements of all variables were taken every fourth minute to secure base line readings. All measurements were taken in a room next to the experimental room, from where the subjects, who were alone, could be observed through a one-way screen, and the hand immersions directed with light signals.

During the immersions and the intervals in between, blood pressure was measured once every minute at the end of the minute (at 45 secs.). Heart rate was measured from the 35th to the 55th second of each minute. After the last exposure, measurements were taken each minute for four minutes. After this, two more measurements were taken at four minute intervals, and the experiment was complete.

The temperature of the experimental room was thermostatically regulated and set at 26.5°C , around which room temperature varied $\pm 1^{\circ}$. The subjects were naked except for cotton shorts. They were informed about the nature of the experiment beforehand and were made acquainted with the experimental set up, and had several blood pressure measurements taken before the actual testing. Test I and II were taken between 8 a.m. and 12 noon, and test III in the afternoon between 2 and 5 p.m. on the same day as test I. Subjects were inactive some hours before testing, and had not eaten for one hour before testing. After test I and test II, the subjects were asked which of the six exposures they considered had been the most and the least uncomfortable.

Results

A. Systolic Blood Pressure.

Table 1 shows that the resting systolic pressure did not change significantly for either group from the tests before the experimental period to the tests after.

Table 1.

Mean resting systolic blood pressure in mm Hg for all experiments before and after the training and general cold exposure.

Group	Before	SE	After	SE	Diff.
Cold	111.4	3.29	109.7	2.07	- 1.7
Warm	108.0	1.43	108.3	1.66	0.3

Table 2 shows a decrease of the systolic pressor reaction after the experimental period for both groups. In experiment I the decrease is significant at the .05 level only for the cold group. In experiment II the reduction is significant at the .01 level for the warm group, but falls just beneath the .05 level for the cold group. In experiment III the decrease is again significant at the .05 level only for the cold group, as can be seen in Table 3. The differences in decrease between the cold and the warm group are not significant.

Table 2.

Mean rise of systolic blood pressure in mm Hg during six exposures of one minute with intervals of one minute of left hand to ice water before and after the physical training and general cold exposure. Experiment II is a duplication of experiment I.

Experiment I

Group	Rise before	SE	Rise after	SE	Decrease
Cold	18.0	2.63	10.8	2.63	7.2
Warm	15.9	2.64	12.3	1.79	3.5

Experiment II

Group	Rise before	SE	Rise after	SE	Decrease
Cold	15.5	3.15	10.6	2.99	4.9
Warm	15.8	2.50	10.2	1.83	5.6

Table 3.

Mean rise of systolic blood pressure in mm Hg during one exposure of 2 minutes of right hand to ice water before and after the physical training and general cold exposure.

Experiment III

Group	Rise before	SE	Rise after	SE	Decrease
Cold	17.6	3.47	11.0	3.07	6.6
Warm	15.5	2.63	13.8	1.85	1.7

In fig. 2 the results of Experiment I is plotted for both groups.

Fig. 3 shows the mean increase of systolic pressure for each of the six successive exposures for both groups before the experimental period. The pattern was the same after the experimental period but at a reduced scale. The fig. shows that exposures II and III give the greatest pressor reactions, being significantly higher than exposure I and exposure IV, V and VI.

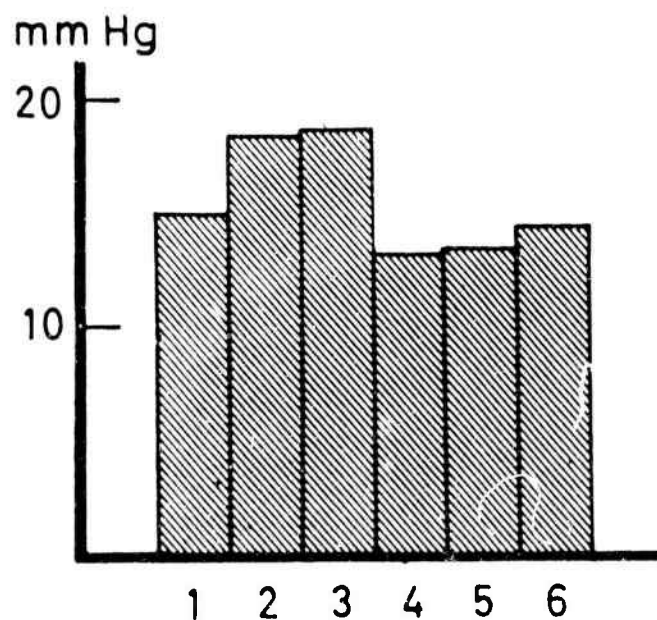


Fig. 3. Mean increase of systolic blood pressure during six successive exposures of the hand to ice water.

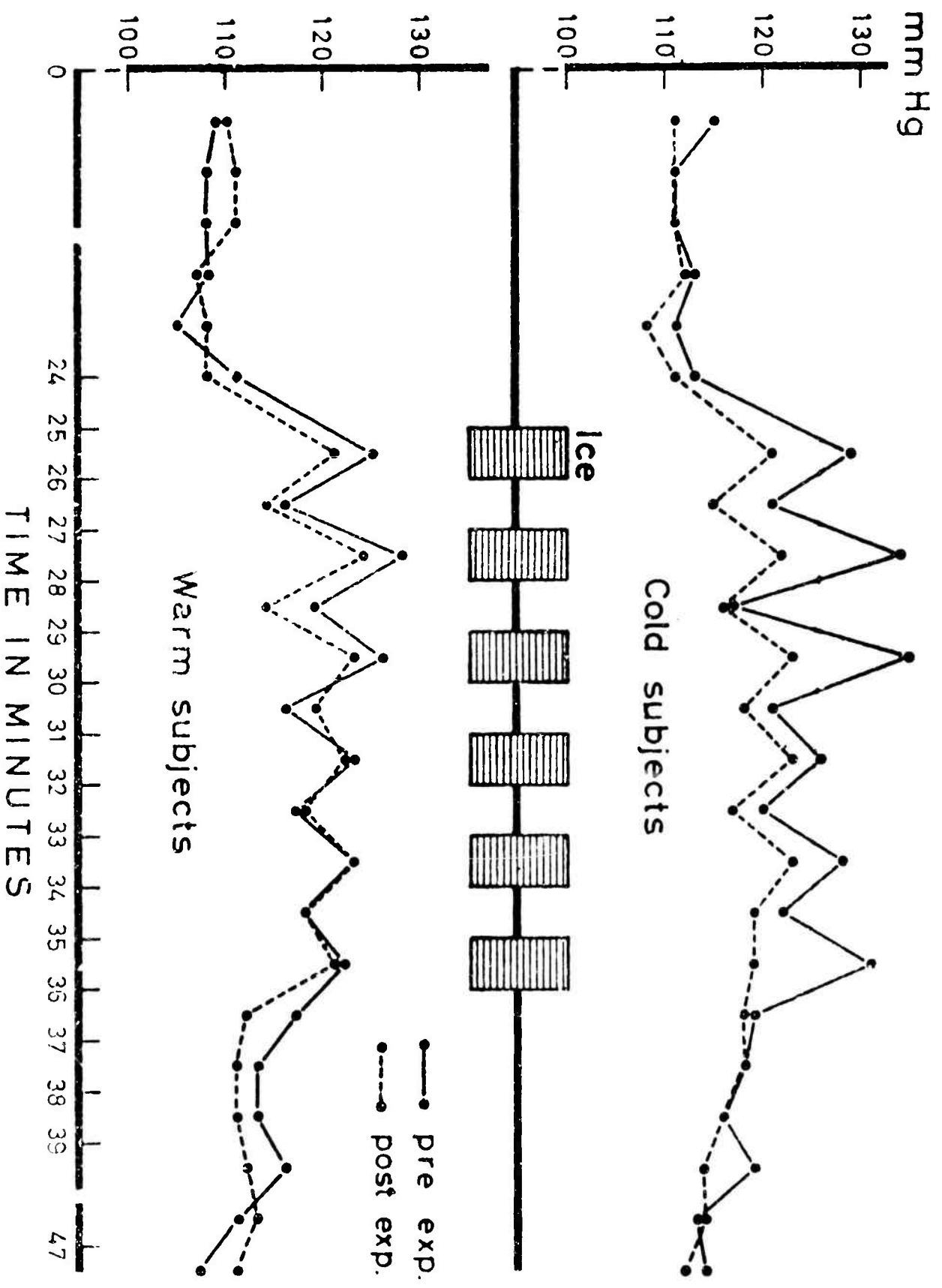


Fig. 2. Mean responses in systolic blood pressure in mm Hg during 6 exposures to ice water of left hand before and after the experimental periode plotted against time.

B. Diastolic Blood Pressure.

For both groups there is a significant reduction of resting diastolic pressure after the experimental period and hence an increase of pulse pressure (Table 4).

Table 4.

Mean resting diastolic blood pressure in mm Hg for all experiments before and after the physical training and general cold exposure.

Group	Before	SE	After	SE	Decrease
Cold	65.6	2.85	57.8	1.75	7.8
Warm	64.0	2.12	58.0	1.10	6.0

The reduction in diastolic pressor reactions is consistently less than for systolic pressure, being significant in one case only, for the cold group in exposure III (Table 6).

Table 5.

Mean rise of diastolic blood pressure in mm Hg during six exposures of one minute with intervals of one minute of left hand to ice water before and after the physical training and general cold exposure. Experiment II is a duplication of experiment I.

Experiment I

Group	Rise before	SE	Rise after	SE	Decrease
Cold	16.3	2.61	15.3	1.54	1.0
Warm	17.2	2.68	14.9	1.63	2.3

Experiment II

Group	Rise before	SE	Rise after	SE	Decrease
Cold	17.0	3.50	14.5	1.72	2.5
Warm	15.3	1.28	13.8	1.55	1.5

Table 6.

Mean rise of diastolic blood pressure in mm Hg during one exposure of 2 minutes of right hand to ice water before and after the physical training and general cold exposure.

Experiment III

Group	Rise before	SE	Rise after	SE	Decrease
Cold	17.9	3.39	11.7	2.83	6.2
Warm	19.8	1.92	16.9	2.45	2.9

C. Heart frequency.

There is a slight decrease in heart rate at rest in both groups after the experimental period.

Table 7.

Mean heart rate in beats per min. at rest for all experiments before and after physical training and general cold exposure.

Group	Before	SE	After	SE	Decrease
Cold	69.5	2.96	64.3	0.87	5.2
Warm	67.7	1.68	65.2	2.94	2.5

The cardio-accelerator reaction to the cold tests was very small in all experiments, averaging 2.9 beats/min in the pretests, and there was no significant reduction in reaction after the experimental period in any case.

D. Finger Skin Temperature.

There is a slight but insignificant reduction in skin temperature on the pulpa of the 3rd finger in the preperiods after the experimental period (Table 8).

Table 8.

Mean skin temperature on pulpa of 3rd finger in °C in the pre-periods of all experiments before and after the physical training and general cold exposure.

Group	Before	SE	After	SE	Decrease
Cold	33.03	0.63	31.89	0.37	1.14
Warm	33.46	0.59	33.62	0.43	0.16

There is no significant difference in mean skin temperature of the pulpa of the 3rd finger of the exposed hand during exposures before and after the experimental period in either group (Table 9).

Table 9.

Mean temperature on pulpa of 3rd finger in °C of the exposed hand during six successive exposures to ice water before and after the physical training and general cold exposure. The table includes Experiments I and II.

Experiments I and II

Group	Before	SE	After	SE	Increase
Cold	6.53	0.45	6.40	0.34	-0.13
Warm	6.56	0.29	6.96	0.29	0.40

From fig. 4 it can be seen that finger skin temperature of the exposed hand gradually decreases during the successive exposures at a decreasing rate. Only the pre-experimental data are included in the fig., but the pattern was the same after the experimental period.

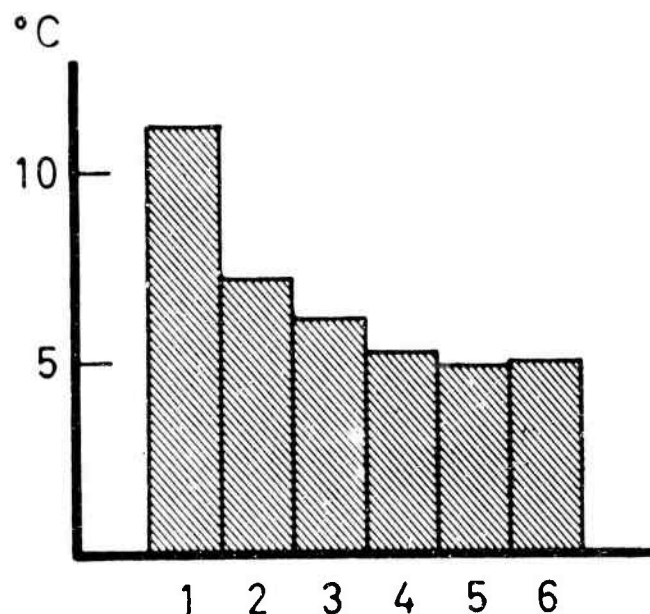


Fig. 4. Mean skin temperature on the pulpa of 3. finger of the exposed hand on 6 successive exposures.

E. Subjective sensations.

An attempt was made to get an estimate of the relative discomfort caused by successive exposures, by asking the subjects which of the six exposures had been the most uncomfortable. The percentage of votes for each exposure is given in fig. 5, which includes the pre-test for both groups. The post-tests showed the same pattern. It will be noted that exposure II was considered the worst by most subjects while exposure I had the lowest percentage. From II to IV there is a decline but at V a rise again, and finally a fall at the IVth exposure.

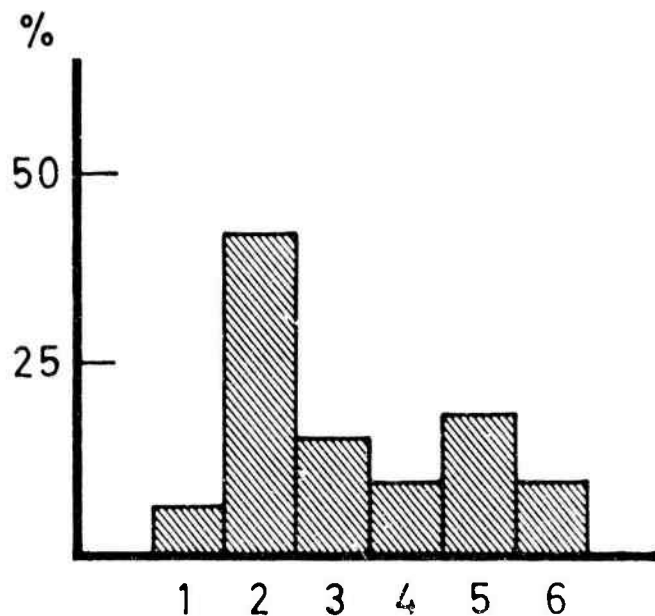


Fig. 5. % judgement of "most uncomfortable" exposure during 6 successive exposures.

Discussion

There is a consistent tendency towards a reduction in systolic pressor reactions after the experimental period in both groups. This tendency is on the whole slightly stronger in the cold than in the warm group, but not consistently, the reduction being greater in the warm group in Experiment II. The difference in reduction between the groups is in no case significant. It must be concluded therefore that the present investigation gives no clear evidence of any effect of general body cooling on systolic pressor reactions.

An interpretation of the reduction in systolic pressor reactions found, could be that the greater familiarity with the experimental situation after the experimental period reduced the anxiety and consequently the pressor reactions. It would be expected, however, if this was the case, that the base line readings would also be lower in the post experiments, and this is not the case for systolic pressure. It seems most reasonable, therefore, to credit the effect mainly to the physical training programme, although the exact nature of such an influence cannot be stated.

The divergencies of results of Experiment I and II, which are duplicated experiments, shew that the cold pressor test is open to the influence of factors which are difficult to control and which reduces the reliability of the test. As a consequence of this variability of the data the conclusion above must be of a tentative character.

The lower resting diastolic pressure in both groups with an increased pulse pressure is probably a result of training. The interpretation of this does not belong here.

There is a consistently smaller reduction in diastolic pressor reactions than in systolic in the post-exp. tests. This is not easily explained. It might somehow be related to the changes in resting diastolic pressure, but the nature of such a relationship is unclear.

The heart rate responses to cooling in the present experiment are less than what has been previously found by Glaser et al. (4, 5) and Griffin (7) for hand exposure to water at 4°C. The explanation of this could possibly be that the heart rate in the present experiment was recorded only in the last half of each minute during exposures. There might possibly have been a greater acceleration in the first half of the minute.

If we consider figs. 3 and 4 we see that there is no direct relationship between finger skin temperature on the exposed hand and the magnitude of the pressor reaction. The stimulus of the pressor reaction does not seem to be the absolute skin temperature, because the reaction does not increase as the temperature decreases. If the stimulus was the thermal gradient between hand skin temperature and water temperature, the reaction could be expected to fall as the gradient falls. Neither this seem to be the case; the reaction to the first exposure (when the gradient is greatest) is significantly smaller than to the second and third exposure. There is also a tendency for the reactions to rise at the end of the sequence, when the gradient is smallest. The picture is further complicated by the process of adaptation which is supposed to account for the reduction

in reaction from the first exposures to the last ones (4). On the basis of the present data it seems impossible therefore to detect the nature of the stimulus of the pressor reactions. The reaction pattern as seen in fig. 3 is probably the combined effect of stimulus changes and adaptatory processes.

The data given in fig. 5 on the subjective experience are not in perfect agreement with the reaction pattern shown in fig. 3. This could indicate that there is no direct relationship between the subjective sensation of discomfort and the pressor reactions. The crude nature of the data on the subjective experience makes it unwarranted, however, to draw such a conclusion. The data seems to indicate, nevertheless, that there are no very distinct and clear-cut changes of sensation during the series of exposures, and there seem to be important individual variations in this respect. We see from fig. 5 that except for a relatively high agreement that number 2 is the worst, there is a wide scatter of judgment of most uncomfortable on all exposures. The subjects also generally expressed much doubt about their choice. It is noteworthy that while some subjects reported a gradual improvement with each exposure of the series, others reported the opposite, and many reported fluctuation of sensations through the series. It is possible that these discrepancies could result from inadequate observations by the untrained subjects, and from differences in the interpretation of "most uncomfortable". It seems however, that the relation of the subjective sensations to cold pressor reactions is still far from clear.

Conclusions

1. A reduction in systolic pressor responses after the training period is found in both groups in all experiments. For the cold group the reduction is significant in Experiment I and III, for the warm group only in Experiment II. The difference between the groups in response reduction is in no case significant. The reduced systolic responses are therefore tentatively interpreted as an effect of the training programme.
2. A consistent reduction in diastolic pressor reactions is found in both groups, but smaller than for systolic pressure, being significant in one case only, for the cold group in Experiment III.

3. Neither the absolute skin temperature nor the thermal gradient of the exposed hand bears a close relationship to the magnitude of the pressor reactions in the present experiments.
4. The eliciting stimulus of the cold pressor reaction and the relation of subjective sensations to the pressor reactions remain unclear.

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VI. GENERAL DISCUSSION

This study shows that tolerance to cold is increased by a period of vigorous physical training in accord with Adams and Heberling's (1) and Keatinge's (2) earlier observations. The trained subjects were able to sleep and rest more comfortably under cold conditions than in the untrained state. The following discussion indicates some of the physiological mechanisms involved.

Basal Metabolic Rate.

The most striking physiological adjustment contributing to an improved reaction to cold was the elevation of the Basal Metabolic Rate. This could be due to a change in body composition, an increase in dietary protein or an increased set for tissue metabolism caused by an increase in endocrine activity particularly of the thyroid gland.

The body weight of our subjects increased by an average of 2.4 kg but since it seems from the skin fold measurements that this was mostly fat it may not contribute much to the elevation in metabolism. Muscle, which is usually considered metabolically more active than fat, was probably increased very little in mass during this training period.

With regard to protein intake, although the composition of the diet remained constant the quantity of food intake increased by approximately 75%. It therefore follows that protein intake was correspondingly increased. Whether this fact alone would lead to an increased basal metabolism is not known.

Little is known about the effects of vigorous muscular exertion upon the activity and functioning of the endocrine glands. The functioning of the thyroid gland was studied quite extensive as part of this investigation, and the results will be reported separately by O. Wilson. Preliminary examination of the data indicates a change in some aspects of thyroid function in both groups of subjects after the period of physical training.

Cold Induced Metabolic Response.

In the standard all night cold exposures, as well as in the warm control nights, the metabolism was higher after the training period - but the difference in metabolic rate between warm and cold nights was

unchanged by the period of physical conditioning. The observations that the electrical activity of muscles in the cold was also increased in both groups after the training period are in keeping with the metabolic data based on oxygen consumption. The observations on metabolic rates are in agreement with those reported by Scholander et al. (3) in similar tests. However the interpretation placed on the earlier observations that the changes seen constituted a metabolic acclimatization to cold is not confirmed in the present study. Certainly the higher metabolism in the cold contributes to the increased tolerance to cold but since it was equally evident in the group of subjects who were trained but not exposed to cold it is clearly related to the physical training regime and not to the cold exposure "per se".

The relationship between electrical activity of muscle and oxygen consumption gave no evidence for the hypothesis advanced by Davis et al. (4) that repeated cold exposure results in an increase in cold induced non-shivering thermogenesis in man.

Whether cold exposure alone without physical training would have any effect on either basal metabolic rate or on cold induced metabolism with or without shivering cannot be answered from the present studies.

Aerobic Capacity and Response to Cold.

Improvement in the maximum oxygen uptake is considered a criterion of improved physical fitness. This implies a relationship between physical fitness and heat producing capacity and therefore also a relationship between improved fitness for muscle work and greater fitness to cope with cold. However the present experiments do not indicate that these two physiological parameters are closely related. The basal metabolic rate increased on average more than the increase in maximal O_2 - uptake, the latter being used as criterion of physical fitness. Furthermore, increased basal metabolism was observed as an effect of the training regimen in two subjects who did not alter their maximal oxygen uptake.

Peripheral Circulation.

Both the 2-hour tests and the all night tests indicated that after the training period all the subjects had an increased peripheral circulation in a comfortably warm or thermo-neutral environment. This finding may be related to the increased metabolic rate already discussed but might also be related to an increased blood volume, or to changes in vasomotor

tone induced by changes in the sympathetic nervous system or the sensitivity of vascular smooth muscle to circulating catecholamines. These latter possibilities have not been tested in these experiments. However physical training has been reported to increase blood volume (5).

However even the apparently mild conditions of cooling used in the 2 hour experiments, (naked at 17°C with little air movement), resulted in almost complete vasoconstriction, and no distinction could be made in either group of subjects between the preliminary and post training tests if the extra stored heat in the limbs be taken into account in the studies of peripheral temperature.

If even milder cooling conditions had been tested differences between the trained and untrained state may have been detected. This gives support to Wyndham's emphasis for using a range of cold environments in testing for cold tolerance (6).

Cold Pressor Response.

Other authors have reported that repeated local severe cooling of a limb depresses the cold pressor response. The intermittent moderate general body cooling associated with vigorous physical training to which our subjects were exposed had only a questionable effect, and the training without cold exposure had little or no effect.

General Significance of the Results.

The general body cooling which half of our subjects experienced every night may be considered to be mild. However, it is believed that the cold stress was of the same magnitude as indigenous people are used to when living in a cold climate. Most of them are probably only occasionally exposed to such uncomfortable cold conditions for any length of time. However, the present study failed to demonstrate any effect of the daily general body cold exposure over and above that induced by physical training. Whether or not more severe general body cooling over a longer period of time, or whether cold exposure alone without the physical training, or whether repeated severe local extremity cooling would have brought about physiological adjustments are open questions.

Most earlier studies dealing with human acclimatization to cold have completely overlooked the possibility that vigorous physical activity may bring about physiological adjustments of significance.

The present studies suggest the possibility that vigorous physical training may be a practical and useful way to increase cold tolerance.